PETROLEUM TECHNOLOGY ALLIANCE CANADA

PTAC

# Analysis and Report of SlipStream® GTS-DeHy Auxiliary Burner System in Glycol Dehydration Units


Prepared by
Frank Zahner P.Eng MBA

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ACCURATA INC.
DIVERSE CONSULTING SERVICES

## Executive Summary

The SlipStream® GTS-DeHy system is a proprietary technology owned by Spartan Controls. It collects the still column vented gasses on glycol dehydrators and uses it for fuel. The system utilizes a main burner and an auxiliary burner mounted in the main burner exhaust stack. The main burner is supplemented using primary fuel gas when the still column vent gas is unavailable. Two field trials were undertaken to demonstrate the operation of the system. This report documents the findings at one of the installations. The second installation continues to operate but the site suffers upsets that currently affect the data quality so its performance evaluation was not included in this report.

Field operating data demonstrates that the heat requirements of the dehydrator are met using the normally vented still column gas more than 98% of the time. We estimated $CO_2e$ reduction of approximately 90 tonnes/annum based on the data collected in February 2016. This estimate is probably not representative since many variables influence the still column vent rates. Based on the same sample data in February 2016 and an assumed natural gas price of $1.60/GJ we estimated a cost recovery of 108 years. This time period may be reduced to 44 years by applying carbon offset credits. Allowing for any penalties that might be applied by regulatory noncompliance would further shorten the cost recovery period. The health costs associated with exposure are also not included in the cost recovery estimate. Economies of scale should reduce the installation cost and improve the economics.

Independent field testing performed by Maxxam Analytics proved that destruction efficiency of the benzene by combustion of the still column vent gas is greater than 99.9%. This system can help Producers maintain a safe work environment and offer a solution for the virtual elimination of vented still column gasses. This feature is the main purpose of the technology. The system has proven that it is a reliable technology that can be used by Operators to virtually eliminate the BTEX vented emissions from Glycol dehydrators. The SlipStream® GTS-DeHy technology is expected to provide a cost effective, reliable solution for BTEX emission elimination from glycol dehydrators.

## Acknowledgements

The author wishes to thank NRCan for providing the funding to complete the study. Spartan Controls Ltd staff who reviewed the calculations and report for accuracy also provided significant contributions. Those Spartan staff members are, in no particular order, Cam Dowler, Howard Malm, Greg Brown, Brian Bobyk, Josh Seeley, Les Keest. Furthermore, the staff members of the Producer's test site, namely Michael Steeves and Carson Mikula provided operating experience to provide perspective to the performance of the installation. Contributions in kind were provided by Bonavista Energy and Repsol Oil & Gas Canada Inc for providing the test sites and installing the SlipStream® GTS-DeHy equipment.

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# Analysis and Report of SlipStream® GTS-DeHy Auxiliary Burner System in Glycol Dehydration Units

Presented by Accurata Inc
March 29, 2016

## 1 Introduction

Accurata Inc was retained by PTAC to undertake a qualification study of the SlipStream® GTS-DeHy system under development by the REM Technology Inc and PIC Divisions of Spartan Controls. The study was funded by NRCan with contributions in kind by Spartan Controls and the Producers who own the test sites; namely Repsol Oil & Gas Canada Inc and Bonavista Energy. One test site is located near Westerose AB and the other test site is located near Wild River AB (about one hundred kilometers north of Hinton AB). Ongoing changes to the Wild River site affected the quality of the test data. The Wild River test data is not included in this report because the issues would not be resolved by the time the report was to be completed.

Producers have limited means for dealing with BTEX (benzene, toluene, ethylbenzene, and xylene) emissions from their dehydrators. The SlipStream® GTS-DeHy Technology was developed to provide natural gas Producers with a way to achieve destruction of virtually all the BTEX emissions from their dehydrators. REM Technology Inc (RTI) claims the SlipStream® GTS-DeHy system provides 99% BTEX destruction efficiency. The system also operates on a continuous basis (which differs from other technologies). RTI, a wholly owned subsidiary of Spartan Controls, has patents pending on the SlipStream® GTS-DeHy technology and offers it as a proprietary system.

## 2 Study Scope

Accurata's scope of work for the study consists of the following tasks.

- Provide a description of BTEX regulations in BC, AB, and SK.
- Describe the operation of the SlipStream® GTS-DeHy system.
- Describe the facilities at the Westerose and Wild River sites and their installation aspects.
- Visit the site of the Westerose facility to witness the operation of the system.
- Obtain Operating records for the Plant and Dehydrators.
- Obtain schematics for the dehydrators if possible.
- Qualify the operation of the system at Westerose with operating data analysis.
- Demonstrate the performance of the system with calculations showing benzene, greenhouse gas and fuel consumption reductions.
- Ascertain reliability of the system.
- Obtain operator statements on ease of operations.
- Determine maintenance requirements from operators and Spartan Controls.
- Determine cost recovery and quantify economic aspects.

Data to support the analysis is captured via remote monitoring software supplied by REMWeb (a web based data capture service offered by RTI). Electronic data verification was achieved by comparison with conditions observed during the site visit. Analysis of the flue gasses, with and without the SlipStream® GTS-DeHy system enabled as well as process and fuel gas sample analysis are provided by others for use in the qualification study.

## 3 Summary of Regulations for Benzene Emissions from Dehydrators

The process of reacting the process gasses with glycol in a dehydrator produces benzene and other volatile organic compounds. The benzene is released upon regeneration of the glycol and vented to atmosphere via the still column vent. The combination of Benzene, Toluene, Ethylbenzene and Xylenes is often referred to as BTEX. The terms benzene and BTEX are often used interchangeably since the compounds are found together. Benzene emissions are known to be carcinogenic. Therefore, Provincial health and safety regulations have been implemented to limit benzene emissions.

Regulations limiting benzene emissions from dehydrators in Alberta, British Columbia and Saskatchewan are based on a recommended practice document developed by the Canadian Association for Petroleum Producers (CAPP). The document is called "Best management Practices for Control of Benzene Emissions from Glycol Dehydrators, June 2006" according to several references in the regulatory guidelines that direct the reader to CAPP's web site. However, the document could not be found on CAPP's website at the time writing this document so we will limit our discussion to the content in the regulatory standards. The relevant Provincial regulatory standards for benzene emissions from dehydrators are as follows.

- British Columbia Oil and Gas Commission (OGC): Information Letter #OGC 07-03, January 15, 2007; SUBJECT: Benzene Emissions from Glycol Dehydrators
- Alberta Energy Regulator (AER): Directive 039: Revised Program to Reduce Benzene Emissions from Glycol Dehydrators January 22, 2013
- Government of Saskatchewan Ministry of Economy (ECON): Guideline to Reduce Benzene Emissions from Glycol Dehydrators, Guideline S-18, November 1, 2015 Revision: 2.0

Most elements of the guidelines are common to all three provinces. These elements include detailed clauses that advise how to qualify the emissions at a site and what limits to apply. We show the tables and clauses from AER's directive 039 below. The other two provinces require the same measures (except the dates required for the annual inventory filing requirement will vary by province).

> "1) Licensees must follow the public consultation process outlined in the most recent edition of the Canadian Association of Petroleum Producers (CAPP) document Best Management Practices for Control of Benzene Emissions from Glycol Dehydrators (Benzene Control BMP).
>
> When evaluating dehydration requirements in order to achieve the lowest possible benzene emission levels, licensees should use the Decision Tree Analysis in Appendix A of the Benzene Control BMP and retain appropriate analysis documentation for review by regulatory agencies.
>
> 2) Licensees must ensure that all their dehydrators do not exceed the benzene emission limits for each dehydrator, based on the applicable calendar year, as outlined in Table 1. Licensees must verify the distance from an emission source to the nearest permanent residence or public facility to ensure that all requisite changes to the dehydrator are made and emission levels assessed.

**Table 1. Grandfathered glycol dehydrator benzene emission limits**

| Date dehydrator installed or existing dehydrator relocated | Benzene emission limits |
|---|---|
| Prior to January 1, 1999 | |
| • Greater than 750 m to permanent resident or public facility | 5 tonnes/yr |
| • Less than 750 m to permanent resident or public facility | 3 tonnes/yr |
| January 1, 1999, to January 1, 2007 | 3 tonnes/yr |
| After January 1, 2007 | 1 tonne/yr |

i) If more than one dehydrator is located at a facility or lease site, the cumulative benzene emissions for all dehydrators must not exceed the limit of the dehydrator with the highest emission limit on that site. Modifications may be required to existing unit(s) to meet the site limit.

ii) Any new or relocated dehydrators added to an existing site with dehydrator(s) must operate within maximum benzene emission limit. The cumulative benzene emissions must not exceed the limit of the dehydrator with the highest emission limit on that site.

iii) For dehydrators that are only in operation for a portion of the year, the average daily emission rate must not exceed the above annual benzene emission limits divided by 365. (For example, for a dehydrator with an annual benzene emission limit of 3 tonnes that only operates for six months of the year, the maximum annual emission limit would be 1.5 tonnes or an average maximum daily emission rate of 8.2 kg/day.) See Section 2.3 of the Benzene Control BMP for details on calculating and reporting of emissions from dehydrators that only operate a portion of the year.

3) Licensees must complete a Dehydrator Engineering and Operations Sheet (DEOS) (Attachment 1) to determine the benzene emissions from each dehydrator. This sheet summarizes a dehydrator's average operating conditions and estimates benzene emissions for up to a 12-month period following the DEOS "Revision Date" and must be posted at the dehydrator for use by the operations staff and inspection by the ERCB. The DEOS must be revised every 12 months, upon relocation, or upon a change in status (resume operation, shut-in, bypassed) of the dehydrator.

4) Licensees must complete and submit by May 1 of each year an annual Dehydrator Benzene Inventory List for the operations of the previous calendar year (Attachment 2), listing all the licensee's dehydrators. This information must be submitted to the ERCB as an Excel file by e-mail to BenzeneD39@ercb.ca.The annual Dehydrator Benzene Inventory List form is available on the ERCB Directive 039 webpage."

Alberta imposes more detailed regulations on the emissions limits. The following clauses and tables are present in AB Directive 039 but are not found in BC and SK regulations.

"2) Licensees must ensure that all their dehydrators do not exceed the benzene emission limits for each dehydrator, based on the applicable calendar year, as outlined in Table 1, Table 2, or Table 3.

Unless Table 2 or Table 3 applies to a dehydrator, benzene emission limits must comply with Table 1. The implementation schedule in Table 2 sets out the updated emission limits at the beginning of the listed calendar year for a dehydrator based on the distance from the emission source to a permanent residence or public facility. Licensees must verify the distance from an emission source to the nearest permanent residence or public facility to ensure that all requisite changes to the dehydrator are made and emission levels assessed.

The implementation schedule in Table 2 ensures continuous reductions until all existing dehydrators operate within the updated emission limits by January 1, 2018, as set out in Table 3. As of January 1, 2014, all new or relocated dehydrators must not exceed the emission limits specified in Table 3. To qualify for the emission limits for an appropriately designed flare or incinerator, a flare or incinerator must be used that meets the minimum performance requirements in Directive 060, Section 7.

If a dehydrator requires changes to comply with the updated emission limits, the licensee should consider the implications of making multiple changes to comply with the successive reductions set out in Table 2 and are encouraged to upgrade each dehydrator only once to meet the limits in Table 3.

**Table 2. Implementation schedule and updated annual benzene emission limits for degrandfathering glycol dehydrators based on distance to a permanent residence or public facility**

| Implementation schedule by calendar year to reduced emissions | | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|
| | Distance in metres (m) | Emission limit required as of January 1 of the calendar year in tonnes (t) | | | | |
| No control or a control other than an appropriately designed flare or incinerator | ≤100 | 0.0 | | | | |
| | 101–250 | 0.1 | | | | |
| | 251–750 | | 1.0* | 0.5 | | |
| | >750 | | | 3.0* | 2.0* | 1.0 |
| After control emission limit for an appropriately designed flare or incinerator** | ≤250 | 1.0 | | | | |
| | 251–750 | | | 1.0 | | |
| | >750 | | | | | 3.0 |

* Licensees are encouraged to upgrade each dehydrator only once to meet Table 3 limits and to consider the implications of making multiple changes to meet successive reductions as outlined in Table 2.
** An appropriately designed flare or incinerator must meet the performance requirements in Directive 060, Section 7.

**Table 3. Calendar-year emission limits for all glycol dehydrators effective January 1, 2018**

| Reduced benzene emission requirements | | |
|---|---|---|
| | Distance in metres (m) | Emission limit in tonnes (t) in each calendar year |
| No control or a control other than an appropriately designed flare or incinerator | ≤100 | 0.0 |
| | 101–250 | 0.1 |
| | 251–750 | 0.5 |
| | >750 | 1.0 |
| After control emission limit for appropriately designed flare or incinerator source | ≤750 | 1.0 |
| | >750 | 3.0 |

”

Review of the benzene reduction requirements in BC, AB and SK show common elements. In general, the basic elements of the regulations involve four main tasks for dehydrator operators.

a. Evaluate the volume of emissions using a decision tree analysis to produce the minimum volume of emissions with a public consultation process.
b. Determine benzene emission limits based on age and location for each installation and the guidelines for combining numbers of dehydrators.
c. Prepare a Dehydrator Engineering and Operations Sheet (DEOS) for each installation.
d. Provide an annual dehydrator inventory and emissions report submitted to the Provincial Regulator.

The SlipStream® GTS-DeHy system is designed to virtually eliminate the benzene emissions from one (or perhaps more) dehydrators on a site. This enables the operator more options in meeting their benzene emission limits.

## 4 Description of the SlipStream® GTS-DeHy system

The system relies on the integrated use of two low pressure burners that are fed with gas vented from the still column to fuel the burners. One low pressure burner is the main burner for the glycol bath in the reboiler. However, that burner is not always operating so the emissions released while the main burner is not in operation still need to be captured or managed. The SlipStream® GTS-DeHy system adds an auxiliary low pressure burner located in the stack used for the main burner that is active when the main burner is not operating. The purpose of the auxiliary burner is to combust the remaining still column vent gas.

The existing high pressure burner that operates on process gas (site fuel gas) is replaced with a new burner system. It is activated if the main low pressure burner does not satisfy the process heat requirements. The high pressure and low pressure main burners utilize the same flame tube. Independent burner management systems are provided for each of the main and auxiliary burner. Both burners are equipped with an automated ignitor that utilize plant utility fuel gas. The pilots operate only when, and while, the burners operate. The SlipStream® GTS-DeHy technology includes the following major components.

- SlipStream® control panel
- Two burner management systems
- B149.3 compliant valves valve train for LP and Aux burners
- B149.3 compliant valves valve train for HP burner
- B149.3 compliant Main HP Burner, Main LP Burner, Auxiliary Burner
- Liquids handling system (aerial cooler and gas to gas heat exchanger)

It is important that the gas fed into the burners from the still column is dry. Liquids are removed with an adaptive liquids handling system that includes heat exchangers with variable speed fans. The fan speed is adjusted to maintain the temperature of the waste gas. Liquids are collected in a knock out drum. Figure 1 provides an overview of how the system is assembled. Appendix A provides a detailed description of its operation with each operating mode depicted.

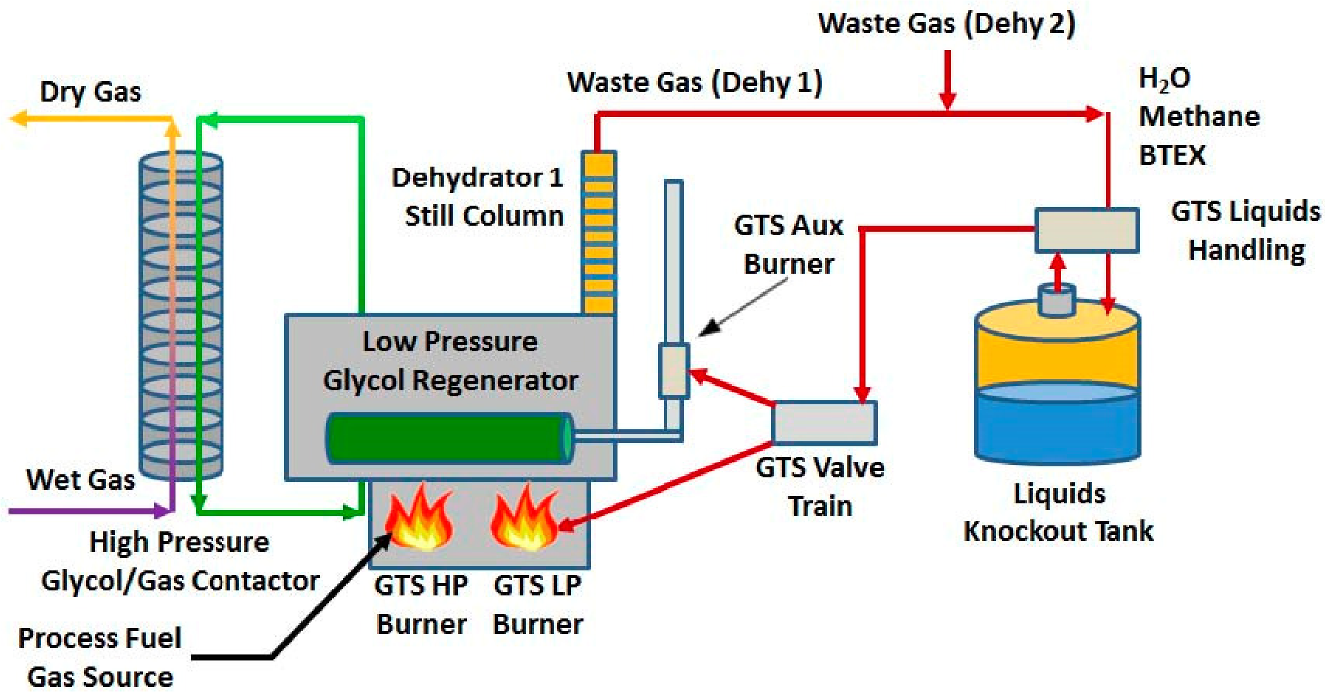



Figure 1: SlipStream® GTS-DeHy operating overview

## 5 Description of the Test Sites

Two Alberta test sites are in service for the SlipStream® GTS-DeHy system. One is located near Wild River and the other is located near Westerose. The installation at the two sites varies in the captured gas cooling arrangement and the liquid knock out tanks. Also, the Wild River site included a gas to gas heat exchanger on the still column vent capture system that was not present on the Westerose installation. The knock out tanks are different at each site because the existing facilities were used for that purpose (as it would be at other sites). Data is collected and presented for each site.

### 5.1 Westerose Site

The Westerose site was installed in October 2015 with commissioning completed on October 28. The site contains two natural gas dehydrators; namely the "North" and "South" unit. Still column vents from both dehydrators are collected and routed to the SlipStream® GTS-DeHy system installed on the "North" dehydrator. The still column vent gas from both units were originally routed through an underground liquids knock-out tank that is connected to a flare stack. The gas was vented to atmosphere at flare stack, creating unpleasant odors. Figure 1 above shows the current configuration of the Westerose site (Dehy 1 is the "North Dehy"). The still column vents are captured from the top of the waste liquids tank. An aerial heat exchanger provides cooling of the gas to drop out liquids. In the event of an upset condition in the North Dehydrator, the auxiliary burner continues to operate. This assures continued destruction of benzene even if the unit is not operating since the vents are tied into one collection manifold. The characteristics of the two units are as follows.

*South Dehy unit (Dehy 2)*

- 200,000 BTU/hr burner
- Electric glycol pump

*North Dehy unit (Dehy 1)*

- 250,000 BTU/hr burner
- Electric glycol pump

A pictorial presentation of the installation of the equipment at the Westerose site is provided in Appendix B.

## 5.2 Wild River Site

The Wild River site was installed in December 2015 with commissioning completed on December 11. The site (Plant #1) contains one natural gas dehydrator. The still column vent gas is routed to a TankSafe. The TankSafe is used for the liquid knock out tank. Still column vapors are collected from the TankSafe atmospheric vent. An aerial heat exchanger provides cooling of the gas to drop out liquids plus the gas is warmed again through an additional gas to gas heat exchanger (shell and tube style). Configurations were modified at Wild River Site to see if the additional warming of the gas was needed to reduce the amount of liquid formation in the vent gas collection piping. The characteristics of the dehydrator is as follows.

*Plant #1 Dehy unit*

- 280,000 BTU/hr burner
- Kimray glycol pump (gas driven)

It should be noted that the pneumatic pump vents relatively large amounts of gas which often find their way into the fuel supply for the burners. The pumps can stick and operate in a sporadic fashion. This results in variable glycol flow rates and variable vent gas flow rates. The operation of the dehydrator is affected by instability in performance and variable demand on the burner management system. At the Wild River site these issues created upset situations and data which was not representative of the SlipStream® technology. Thus, discussion on the performance of the Wild River site will not be included in this report. A pictorial presentation of the installation of the equipment at the Wild River site is provided in Appendix C.

# 6 Data Collection Summary and Analysis

The author visited the Westerose site on March 03 2016 to view the GTS-DeHy system in operation. The system was functioning at the time. Pressures and temperatures were reviewed and compared with electronic logs to validate our readings. The weather was mild on the day of our site visit with ambient temperature about 6 $^0$C. The operator was kind enough to walk us through the system and the Plant. Spartan Controls also provided a representative to answer questions.

Our objective for the data analysis was to qualify the operation of the GTS-DeHy system. The dehydrator should continue to function as intended. The water content of the gas leaving the dehydrator should also be suitable for the sales line. The quality of the gas leaving the facility should be unchanged or better than before the GTS-DeHy system was installed. To verify these aspects we collected data on the following aspects.

- Function of the control systems on the burners using electronic data records.
- Combustion efficiency of the benzene destruction using gas analysis of feed gas and exhaust gas.
- Fluid analysis of the TEG used in the dehydrator to ascertain that the water content has not changed since the installation of the GTS-Dehy system.
- Operator comments on the system operation.

## 6.1 Plant Operating Characteristics

The Westerose site consists of inlet separation and three compressors running in parallel. From time to time one of the compressors goes down either at this site on one of other sites feeding it. That will produce variable process flow rates for the dehydrators. The process gas is combined from the compressors to flow through both dehydrators in parallel. No flow control is provided to manage the load on each dehydrator. The South Dehydrator is about one third the size of the North Dehydrator. Plots of the North and South Dehydrator parameters and the total plant throughput are provided in Appendix D. Periodic upsets occur every two weeks or so. In general, the Westerose plant is stable.

| Dehydrator | North+South | North | | | South | | |
|---|---|---|---|---|---|---|---|
| Statistic | Total Process Flow (1,000 m3/d) | Process Flow Leaving Dehy (1,000 m3/d) | Pressure Leaving Dehy (kPag) | Temperature Leaving Dehy (C) | Process Flow Leaving Dehy (1,000 m3/d) | Pressure Leaving Dehy (kPag) | Temperature Leaving Dehy (C) |
| Min | 0.0 | 0.0 | 6732.3 | 18.0 | 0.0 | 6702.2 | 9.3 |
| Max | 314.5 | 200.0 | 8321.1 | 38.7 | 115.3 | 8351.2 | 37.8 |
| Median | 198.7 | 149.4 | 7421.5 | 29.2 | 49.5 | 7427.3 | 27.1 |
| Mean | 200.6 | 149.8 | 7412.9 | 29.3 | 50.9 | 7419.4 | 27.1 |
| Stadard Deviation | 24.6 | 12.7 | 146.9 | 2.1 | 12.7 | 146.3 | 2.6 |
| Number of Data Points | 1674 | 1673 | 1673 | 1463 | 1675 | 1675 | 1459 |

Table I: Statistics on Plant Flow and Pressure (January 01 to March 10 2016)

## 6.2 GTS-DeHy System Performance

Electronic data logs were provided by Spartan Controls. These logs varied in granularity and frequency. We did not have continuous data that extended from October 2015 through March 2016 but the data supplied spanned a representative time frame. The data sample, reinforced by the operator’s comments, was complete enough to understand that the system operated continuously and reliably.

We reviewed the data provided and sorted out which data was representative of normal operations. The first three to four months of operation included tuning of the equipment and software. Some Plant upsets were also present including power failures. Spartan had the system tuned in February and March so we selected data during that time period as samples of system performance. A daily log in February shows that the system was operating continuously and when the vent gas was consumed for the main and auxiliary burners (see Table II).

A logic diagram is presented in Appendix E that shows how the system is designed to operate. A plot of the system operation is also presented in Appendix E that is derived from the electronic log data shown in Table II. Features of the system operation that should be noted are that the main burner runs only when vent gas is not available for fuel. Also, the demand for heating is based on the set temperature of the glycol bath in the reboiler. The reboiler glycol temperature is key to maintaining efficient dehydrator operation. Observation of the plot clearly shows that the system is functioning as expected and that the glycol temperature in the reboiler is maintained as required.

Finally, the auxiliary burner operates when vent gas is available but the main burner is not running. The February figures show that the main burner is firing about 41% of the time and consumes about 99.5% of the vented gas. The auxiliary burner burns the remaining vent gas. In that fashion, the destruction of all BTEX is assured as long as upsets do not force the venting of still column gas to atmosphere.

| Date | Time | Hours of Fuel Gas Consumption in the Main Burner | Hours of Vent Gas Consumption in the Main Burner | Hours of Vent Gas Consumption in the Auxiliary Burner | Total Hours of Vent Gas Consumption | Operating Hours for the System | Mass of Vent Gas Burned in the Main Burner over the Previous Day (kg) | Mass of Vent Gas Burned in the Auxiliary Burner over the Previous Day (kg) | Mass of Total Vent Gas Burned over the Previous Day (kg) |
|---|---|---|---|---|---|---|---|---|---|
| 2/1/2016 | 8:43:51 | 0.16 | 9.51 | 0.07 | 9.58 | 24 | 42.55 | 0.25 | 42.8 |
| 2/2/2016 | 8:43:51 | 0.02 | 9.66 | 0 | 9.66 | 24 | 43.41 | 0 | 43.41 |
| 2/3/2016 | 8:43:50 | 0 | 9.98 | 0 | 9.98 | 24 | 44.26 | 0 | 44.26 |
| 2/4/2016 | 8:43:50 | 0 | 10.03 | 0 | 10.03 | 24 | 44.36 | 0 | 44.36 |
| 2/5/2016 | 8:43:50 | 0 | 9.58 | 0 | 9.58 | 24 | 42.64 | 0 | 42.64 |
| 2/6/2016 | 8:43:49 | 0 | 9.65 | 0.01 | 9.66 | 24 | 44.98 | 0.05 | 45.03 |
| 2/7/2016 | 8:43:49 | 0.53 | 10.37 | 0.09 | 10.46 | 24 | 48.04 | 0.32 | 48.36 |
| 2/8/2016 | 8:43:49 | 0.05 | 9.82 | 0.29 | 10.12 | 24 | 46.12 | 1.12 | 47.24 |
| 2/9/2016 | 8:43:49 | 0 | 9.9 | 0.04 | 9.94 | 24 | 46.48 | 0.16 | 46.64 |
| 2/10/2016 | 8:43:48 | 0.26 | 9.36 | 0.14 | 9.51 | 24 | 59.74 | 0.38 | 60.11 |
| 2/11/2016 | 8:43:48 | 0 | 10.02 | 0 | 10.02 | 24 | 78.66 | 0 | 78.66 |
| 2/12/2016 | 8:43:48 | 0.07 | 9.7 | 0 | 9.7 | 24 | 49.48 | 0 | 49.48 |
| 2/13/2016 | 8:43:48 | 0.11 | 10.21 | 0.02 | 10.23 | 24 | 43.11 | 0.05 | 43.16 |
| 2/14/2016 | 8:43:48 | 0 | 9.55 | 0 | 9.55 | 24 | 41.28 | 0 | 41.28 |
| 2/15/2016 | 8:43:47 | 0 | 9.46 | 0 | 9.46 | 24 | 41.14 | 0 | 41.14 |
| 2/16/2016 | 8:43:48 | 0.02 | 9.53 | 0 | 9.53 | 24 | 40.17 | 0 | 40.17 |
| 2/17/2016 | 8:43:47 | 0.06 | 9.46 | 0 | 9.46 | 24 | 39.72 | 0 | 39.72 |
| 2/18/2016 | 8:43:47 | 1.36 | 8.64 | 0.52 | 9.16 | 24 | 37.19 | 1.92 | 39.11 |
| 2/19/2016 | 8:43:47 | 0.42 | 9.49 | 0 | 9.49 | 24 | 39.73 | 0 | 39.73 |
| 2/20/2016 | 8:43:47 | 0 | 9.78 | 0 | 9.78 | 24 | 40.43 | 0 | 40.43 |
| 2/21/2016 | 8:43:46 | 0 | 9.92 | 0 | 9.92 | 24 | 42.44 | 0 | 42.44 |
| 2/22/2016 | 8:43:46 | 0 | 10.13 | 0.08 | 10.21 | 24 | 44.42 | 0.29 | 44.71 |
| 2/23/2016 | 8:43:46 | 0 | 10.01 | 0 | 10.01 | 24 | 42.9 | 0 | 42.9 |
| 2/24/2016 | 8:43:46 | 0.11 | 8.88 | 0.05 | 8.93 | 24 | 36.74 | 0.18 | 36.92 |
| 2/25/2016 | 8:43:46 | 0 | 9.12 | 0 | 9.12 | 24 | 38.25 | 0 | 38.25 |
| 2/26/2016 | 8:43:45 | 1.25 | 8.36 | 0.02 | 8.38 | 24 | 31.86 | 0.05 | 31.91 |
| 2/27/2016 | 8:43:45 | 0.51 | 8.98 | 0.08 | 9.07 | 24 | 36.62 | 0.27 | 36.88 |
| 2/28/2016 | 8:43:45 | 1.16 | 8.51 | 0.05 | 8.56 | 24 | 32.94 | 0.14 | 33.08 |
| 2/29/2016 | 8:43:44 | 3.63 | 7.78 | 0.22 | 8 | 21.73 | 29.19 | 0.67 | 29.85 |
| Totals | | 9.72 | 275.39 | 1.68 | 277.1 | 693.73 | 1,248.85 | 5.85 | 1,254.67 |
| Percent of Totals | | 1.40% | 39.6% | 0.24% | 39.8% | 99.7% | 99.5% | 0.47% | |
| Total days | 29 | Total Hours | 696 | | Flow Rate (kg/h) | | 4.535 | 1.680 | 4.528 |

Table II: SlipStream® GTS-DeHy operating aspects and vent flow rates in February 2016

## 6.3 Dehydrator Functionality

We requested operating data for the dehydrators for periods before and after the installation of the SlipStream® GTS-DeHy system. Our objective was to compare the data to demonstrate that the new system managed the dehydrators to perform their tasks without change to the water content of the gas. Table III below shows test results of the rich and lean glycol in April 2015 before the installation of the system and then on two dates after the installation of the system.

The test report for April 2015 showed that the glycol was contaminated and had high pH Levels for both samples. The testing agency recommended adding corrosion inhibitors and reviewing the glycol bath temperature (the comments implied that it was too low). The results prior to the installation show that TEG maintenance was required and therefore they are probably not representative of how the dehydrators normally performed. The previous control system configuration is not known to the author.

Test results of the glycol after the system was installed show that the North dehydrator is removing about 3.3 wt% water. The glycol bath temperature is typically maintained between 190ºC to 198ºC. That does show that the dehydrator is functioning normally. The enhanced automation features of the new control system should provide improved visibility of the dehydrator performance parameters for the operator over conventional burner controls.

| Test Date | North Dehydrator | | South Dehydrator | |
|---|---|---|---|---|
| | Lean Sample | Rich Sample | Lean Sample | Rich Sample |
| **April 23 2015** | 1.6 | 2.6 | 3.0 | contaminated |
| **February 17 2016** | 2.2 | 5.5 | | |
| | 2.2 | 5.5 | | |
| | 2.3 | 5.5 | | |
| **March 02 2016** | 2.34 | | 3.32 | |

Table III: Glycol Sample Test Results (wt%) (GTS-DeHy installed October 2015)

## 6.4 BTEX destruction

Maxxam Analytics was retained to assess the combustion efficiency. Exhaust samples were collected and analysed in the laboratory. Exhaust velocities and the short duration of the burner operation did not allow tests performed using the traverse of the exhaust stack as normally performed for field tests. EPA Method 19 was employed instead to estimate the exhaust components using the raw gas composition for input. This method is acceptable for EPA test procedures and the methods employed were approved by the AER and Maxxam Analytics. The chromatographic exhaust sample analysis was produced using Method 18. Destruction efficiency of the benzene was assessed using various scenarios. Appendix F shows the final results for the scenarios tested. Benzene average destruction efficiency of 99.975% was achieved for all mode of operation.

The DEOS (Dehydrator Engineering and Operations Sheet) for the site with the previous burner configurations specified that the combined benzene emissions for the two dehydrators is 2.3036 tonnes/year. That emission rate exceeds the required 1 tonne/year regulatory limit for the total benzene emissions for the site. The Operator installed the SlipStream® GTS-DeHy system in order to realise regulatory compliance.

# 7 Operator Comments

The operator at the Westerose site advised us that the SlipStream® GTS-DeHy required very little attention. He also mentioned that the odor associated with the still column vents was no longer present. Low points fitted with drains that are built into the gas collection piping specifically to trap liquids needed to be drained, but only if the aerial cooler fan was not operating. Liquids would collect in the piping in this case instead of the waste tank. Power faults had caused the cooler fan to stop running for a time.

The Westerose system relies on the heat tracing to warm up the gas after the aerial cooler and ensure it is above dew point temperature before entering the burner. However, this winter has not been as cold as normal so that might affect operation in future with colder winter temperatures. Heat tracing of the piping with insulation is a key element to maintaining the gas temperature above the dew point on cold winter days.

Reliability was said to be excellent. Additional parts and pieces are necessary for the new system but they did not present any reliability or maintenance issues. The control systems and PLC's all functioned without faults. Any alarms were easy to acknowledge and those were caused by issues elsewhere in the plant (i.e. not with the GTS-DeHy system). The control panel is intuitive and easy to operate. A graphic on the screen shows which burner is operating and when. The Operator at Westerose had no negative comments.


Photo 1: Spartan Control Panel showing Main Burner Running (green colored valve)

## 8 Greenhouse Gas Reduction and Economics Estimates

Greenhouse gas emissions were reduced with the installation of the SlipStream® GTS-DeHy system. The reduction was achieved by using the still column vents for fuel which replaced most of the primary fuel gas consumption. Table IV below show the details of our calculations. The primary fuel gas was not metered so we estimated the flow rate using the SlipStream® flow measured flow rate and adjusting the value for mass and heating value differences. In so doing it was assumed that the burner uses the same amount of energy regardless of the fuel source. The total fuel consumption is also adjusted for the amount of time combustion is demanded. The data for February presented in Table II provided the basis for our estimates.

It should be noted that the sample consists of one month of data in what is normally one of the coldest months of the year. Vent rates will be affected by a variety of variables including ambient temperature, the quality of the TEG fluid, the glycol bath temperature, the volume of gas processed and the head room in the waste liquids tank. Clearly, a more comprehensive sample taken over the span of one year would be necessary to provide a representative estimate. Extrapolating the data from February alone will likely understate the total vented gas emitted over the course of a year. This would also apply to the $CO_2e$ estimates since gas compositions and process efficiency should vary throughout the year.

The $CO_2e$ estimates shown in the table are estimated using the following equation.

IPCC Method: $CO2e = 310 * N2O + 25 * CH4 + \sum Fuel\ Gas\ Carbon\ Elements$

The $N_2O$ was neglected because combustion efficiencies should be efficient enough to avoid formation of $N_2O$. The gas is normally produced when the exhaust emissions are treated with a process like a catalytic element. Measuring $N_2O$ is also very problematic in field conditions or even in the lab.

Two methods of calculating the $CO_2e$ are employed. Summing the carbon elements was employed when modeling the combustion products from the fuel gas since most of the carbon elements are assumed to produce $CO_2$. Complete combustion is assumed in this case without accounting for unburned hydrocarbons. The exhaust gas analysis showed that the contribution of unburned hydrocarbons was insignificant. The second method is employed for venting the raw gas to atmosphere. In this the contributions of $CO_2$ and $CH_4$ are considered.

The $CO_2e$ emissions prior to the installation of the SlipStream® system are based on burning primary fuel gas in the main burner plus venting all the still column vents to atmosphere. After the installation of the system the emissions are based on combusted vent gas emissions in the main burner and the auxiliary burner plus a small contribution from combustion of primary fuel gas. The contribution of the pilot gas in the main burner and auxiliary burner are also included. The original installation incorporated a continuous pilot that was assumed to consume 30,000 BTU/h. The new installation includes pilots with automatic ignitors. The new pilots will burn for the duration of their respective burners' operation plus an additional 10 seconds. Observing the graph in Appendix E shows that the main burners operated 22 times in three hours. This frequency was employed to estimate the added time that the pilots burned in addition to the main burners. The pilots all utilize the site utility fuel gas supply. Detailed calculations are shown in Appendix G.

No venting of raw gas is assumed since the system normally would combust all the vented gas. If the system shuts down then it will likely be from an upset condition that shuts in the plant as well, in which case venting should not continue. It is assumed that good maintenance practices are applied to provide 100% reliability. The duration of combustion is defined by the frequencies shown in Table II. The approximate emissions estimates we calculated using these assumptions yields a $CO_2e$ reduction of 90 tonnes/annum.

| Source of Emission | | Fuel for Combustion | | | | | Gas Vented to Atmosphere | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fuel Gas for Main Burner | Pilot Gas for Main Burner | Still Column Vent for Main Burner | Pilot Gas for Aux Burner | Still Column Vent for Aux Burner | Fuel Gas for Main Burner | Still Column Vent for Main Burner | Still Column Vent for Aux Burner |
| Before GTS-DeHy Installation | Fraction of time for demand | 0.41 | 1 | 0 | 0 | 0 | 0 | 0.40 | 0.0024 |
| | Mass Flow Rate (Kg/h) | 4.83 | 0.6 | 0 | 0 | 0 | 0 | 4.53 | 3.48 |
| | Ratio for mass and LHV | 0.81 | 1.00 | 1.00 | 1.00 | 0 | 0 | 1.00 | 1.00 |
| | Adjusted Mass Flow Rate | 3.92 | 0.60 | 0.00 | 0.00 | 0 | 0 | 4.53 | 3.48 |
| | GHG Emissions ($CO_2e$) | 37.6 | 14 | 0 | 0 | 0 | 0 | 94.8 | 0.4 |
| | Total $CO_2e$ (tonnes/y) | 147 | | | | | | | |
| After GTS-DeHy Installation | Fraction of time for demand | 0.014 | 0.43 | 0.40 | 0.0024 | 0.0024 | 0 | 0 | 0 |
| | Mass Flow Rate (Kg/h) | 4.53 | 1.62 | 4.53 | 0.19 | 3.48 | 0 | 0 | 0 |
| | Ratio for mass and LHV | 0.81 | 1.00 | 1.00 | 1.00 | 1 | 0 | 0 | 0 |
| | Adjusted Mass Flow Rate | 3.68 | 1.62 | 4.53 | 0.19 | 3.48 | 0 | 0 | 0 |
| | GHG Emissions ($CO_2e$) | 1.20 | 16.38 | 39.26 | 0.01 | 0.18 | 0 | 0 | 0 |
| | Total $CO_2e$ (tonnes/y) | 57 | | | | | | | |
| GHG Contribution Coefficients | Carbon Fraction | 0.72993 | 0.72993 | 0.68118 | 0.72993 | 0.68118 | 0.72993 | 0.68118 | 0.68118 |
| | CO2 Fraction | 0.04962 | 0.04962 | 0.19891 | 0.04962 | 0.19891 | 0.04962 | 0.19891 | 0.19891 |
| | CH4 Fraction | 0.63843 | 0.63843 | 0.23322 | 0.63843 | 0.23322 | 0.63843 | 0.23322 | 0.23322 |
| GHG Emission Change | CO2e Reduction (tonnes/y) | **90** | | | | | | | |

Table IV: CO2e Reduction Estimate

Finally, an estimate of the cost savings can be attempted using the same assumptions and measured values. Table IV below shows the cost recovery estimated at 108 years using an assumed natural gas price of $1.60/GJ. That time period is reduced to 44 years if the Operator can apply carbon tax offsets to the savings. Also, if penalties are incurred for noncompliance with regulatory requirements then that should be considered in the costs. Please remember that the estimates are based on only 29 days during the coldest part of the year. A sample over an entire year would likely produce more vent gas and improved economics. Finally, the health cost aspects are not factored into the economics. Eliminating virtually all the benzene emissions will be a benefit to all those exposed, often on a daily basis. The estimated cost recovery presented here is thus conservative.

| | | |
|---|---|---|
| Fuel gas savings | 1.46 | kg/h |
| Lower Heating Value | 45.5 | MJ/kg |
| Gas Price | 1.6 | $/GJ |
| Annual savings | $928 | Plus penalties and GHG credits |
| Total Installed Cost | $100,000 | |
| Cost Recovery | 108 | Years |
| Carbon Tax Offset | $15 | per tonne $CO_2e$ |
| Offset Value | $1,348.34 | per year |
| Annual Savings with Offsets | $2,276.63 | Plus penalties |
| Cost Recovery | 44 | Years |

Table V: Approximate Cost Recovery Estimate

## 9 Maintenance Requirements

Maintenance requirements are minimal for the SlipStream® GTS-DeHy system. The following list of major components are repeated from above with the maintenance requirements for each component.

### 9.1 SlipStream® control panel

The control panel is an electronic PLC style control unit. The control panel and its associated modules are housed in a weather proof cabinet. No maintenance is needed for the control modules. Periodic checks of the cabinet seals, the terminal strips and internal components such as the power supplies is recommended. These components normally operate until they fail, which is rare. Failures are monitored and reported along with safety shut downs.

## 9.2 Two burner management systems

Two burner management system controllers are incorporated into the control scheme. The control modules are housed in weather proof cabinets. No maintenance is needed for the control modules. Periodic checks of the cabinet seals, the terminal strips and internal components such as the power supplies is recommended. These components normally operate until they fail, which is rare. Failures are monitored and reported along with safety shut downs.

## 9.3 B149.3 compliant valves valve train for LP, HP and Aux burners

The valve trains contain regulators, hand valves, pressure transmitters, pressure switches, thermocouples, solenoids, flow meters and actuated shut off valves. The electronic devices require calibration annually. The valves and flow meters will require periodic maintenance as soft seats and wear items need to be replaced. The time period for those replacements will vary with use and exposure but the replacement interval is typically stated in years.

## 9.4 Main HP Burner, Main LP Burner, Auxiliary Burner

These burners require adjustment of the air fuel ratio to provide the most efficient combustion. The nozzle size will need to be suited to the fuel gas quality. If the fuel gas quality changes then the burner nozzles may have to be changed. The system comprises several nozzles for the different fuel streams. The burner management systems adapt to changing conditions within the range accommodated by the nozzle. Periodic adjustment of the flame quality may be required. The burners are also B149.3 compliant.

## 9.5 Liquids handling system (air cooler and heat exchanger)

The liquid handling system contains hand valves, thermocouples and an adjustable speed drive for the aerial cooler motor. The electronic devices require calibration annually. The valves will require periodic maintenance as soft seats and wear items need to be replaced. The time period for those replacements will vary with use and exposure but the replacement interval is typically stated in years. The adjustable speed drive may need calibration as components age (distant future).

The heat exchangers and liquid collection vessels may be subject to corrosion. An annual review of the component integrity for corrosion is recommended. This review is specified for containment of the collected liquids alone. The system is not pressure retaining so no regulatory integrity review is required.

# 10 Conclusions and Summary

The SlipStream® GTS-DeHy system is equipped with a main burner and an auxiliary burner mounted in the main burner exhaust stack. The system uses the still column vent gas a fuel for the main burner and, when heating demand is not required, the vent gas is burned in the auxiliary burner. A PLC control panel manages the operation of the electronic burner management systems for the two burners. The panel has built in data logging for all parameters of the system. The panel also displays vent gas flow, GHG reduction and fuel saved. The main burner is supplemented using primary fuel gas when the still column vent gas is unavailable.

We estimated $CO_2e$ reduction of about 90 tonnes/annum based on the data collected in February. This estimate is probably not accurate since a variety of variables influence the still column vent rates. Based on the same sample data in February 2016 and an assumed natural gas price of $1.60/GJ we estimated a cost recovery of 108 years. This time period may be reduced to 44 by applying carbon offset credits and allowing for any penalties that might be applied by regulatory noncompliance. The system has proven that it is a reliable technology that can be used by Operators to virtually eliminate the BTEX vented emissions from Glycol dehydrators.

This technology demonstration was a pilot installation with a total installed cost of approximately $100,000. The installation cost of the technology should decline with increasing economies of scale. Other technologies that eliminate BTEX emissions are equipped with vent capture, liquid handling and compression systems. The captured gas is either reinjected to the process inlet or directed to combustor. These solutions are more complex to operate and install. The SlipStream® GTS-DeHy technology is expected to provide a cost effective, reliable solution for BTEX emission elimination from glycol dehydrators.

The system operates the glycol dehydrator to meet heat requirements and burn all available still column vent gas with a high destruction efficiency. It effectively handles the liquids that form in the collection system for the vent gas. The data collected at site demonstrates that the heat requirements of the dehydrator are met using the normally vented still column gas more than 98% of the time. Independent field testing performed by Maxxam Analytics proved that destruction efficiency of the benzene by combustion of the still column vent gas is greater than 99.9%. This system can help Producers maintain a safe work environment and offer a solution for the virtual elimination of vented still column gasses. The main objective of the system is thus fulfilled.

# APPENDIX A

# SlipStream® GTS-DeHy Technology Description

## 1.2 System Overview

***SlipStream GTS-DeHy*** is a patented product designed to capture still vent gas vented from a glycol re-boiler. The captured still vent gas is either used to fire the re-boiler burner, or is incinerated if there is no need for heat. The ***SlipStream GTS DeHy*** can be added to new units or added as a retro-fit solution which converts the existing dehydrator to a near zero emission system which destroys 98+% of vent emissions. By using the still column vent gas as a fuel source, both an environmental (reduced emissions) and economic (reduced process gas consumption) benefits are created.

Equipment includes a low and high pressure valve train, main burner assembly, auxiliary burner assembly, supervisory SlipStream control panel, and two burner management systems.

The supervisory SlipStream control panel provides permission for the burner management systems to operate. The two BMS (burner management systems) control the burners as follows:

- **Main Burner BMS**:
    - Low pressure main process burner (vent gas)
    - High pressure main process burner (process gas)
- **Auxiliary Burner BMS**:
    - Low pressure auxiliary burner (vent gas)

The ***SlipStream GTS-DeHy*** technology has an auxiliary burner that is inserted in the existing process burner's exhaust stack. The auxiliary burner provides a means of combusting low pressure vented gas when it can not be used to supplement the process burner's fuel supply.

For the ***SlipStream GTS-DeHy*** application, the source of the low pressure vent gas is the still column vent of a natural gas dehydrator. Typically this gas is vented directly to atmosphere or sent to TankSafe where a thief hatch is provided for over pressure protection.

The still column vent gas contains mostly methane, volatile organic compounds, hazardous air pollutants, and is saturated with water. To prevent freezing and liquids from getting into the low pressure valve train a liquids handling system is required. The liquids handling system consists of a gas-to-gas heat exchanger, air cooler and liquid storage tank. The air cooler and liquids storage tank serve to remove excess water from the vent gas, while the heat exchanger warms the gas to prevent any further liquid formation in the downstream piping.

After the vent gases pass through the liquids handling portion of the system, they are routed to the inlet of the low pressure valve train. The low pressure valve train consists of additional filtration elements, a flow and pressure transmitter, inline flame arrestor, pressure safety switches, pressure indicators, temperature/safety shutoff valves and manual isolation valves. The low pressure valve train routes the vent gas to either the auxiliary burner or to the low pressure main burner as required by the SlipStream control.

When the low pressure system is disabled or there is insufficient vent gas available for process heating, the SlipStream control reverts to using process gas via a high pressure valve train. In addition to supplying fuel to the main process burner the high pressure valve train also provides fuel for the auxiliary burner pilot. The high pressure valve train consists of a y-strainer, pressure reducing regulators, pressure safety switches, pressure indicators, safety and temperature control valves, and manual isolation valves.

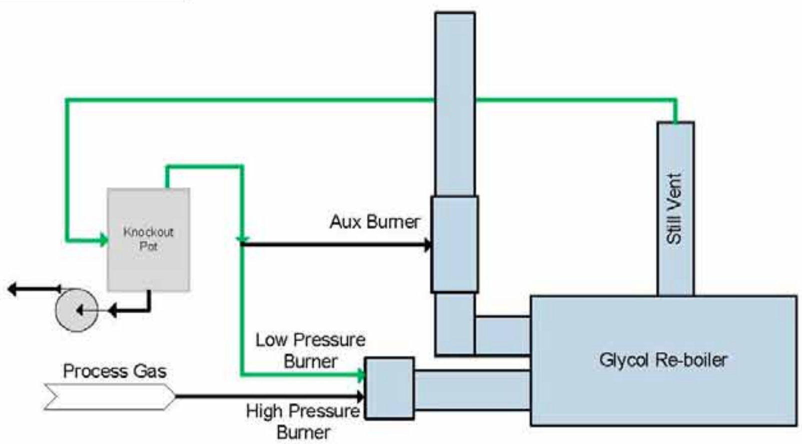
## 1.3 System Operation

The Slipstream GTS DeHy contains three burners:

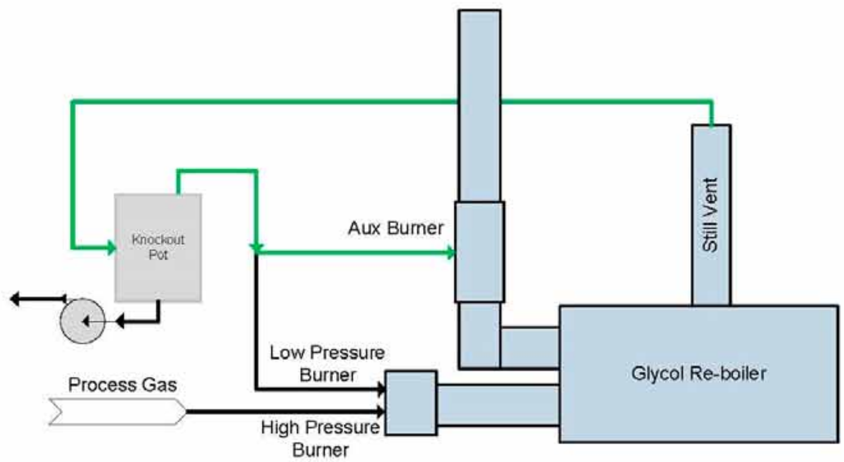
- High pressure burner (HP Burner):
  - located in the main burner
  - operates on process gas (make-up gas)
  - used to heat the glycol bath
- Low pressure burner (LP Burner):
  - located in the main burner
  - operates on vent gas
  - used to heat the glycol bath
- Auxiliary burner:
  - located in the exhaust stack
  - operates on vent gas
  - used burn excess waste gas

The following diagrams show each burner in operation:

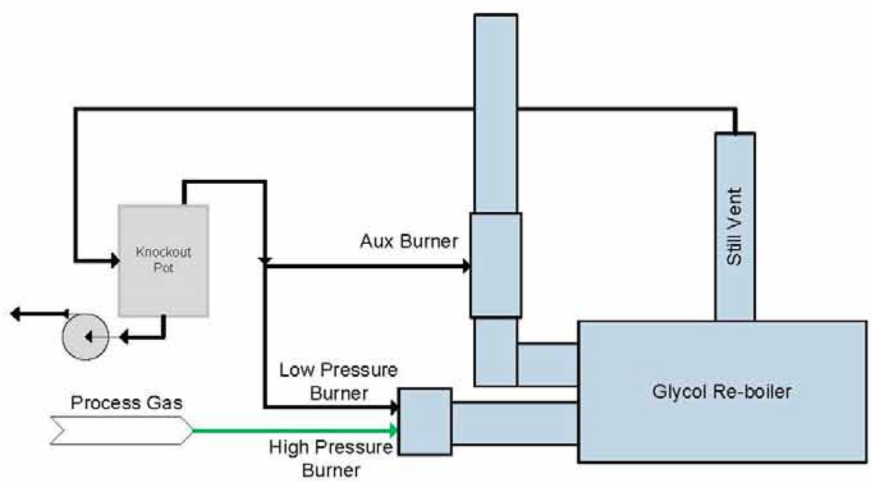
***Low Pressure Burner:***



***Auxiliary Burner:***




***High Pressure Burner:***



# APPENDIX B

## Westerose Installation Details

## Presentation Materials Courtesy of Spartan Controls

## *Westerose South Dehy Unit:*

- 200,000 BTU/hr. burner
- 6" fire tube and exhaust stack
- Electric glycol pump

•

# *Westerose North Dehy Unit:*

- 250,000 BTU/hr. burner
- 8" fire tube and exhaust stack
- Electric glycol pump

.

# Westerose Underground Storage

- Still vent gas from both DeHy units routed to underground liquids knock-out tank..

# Removal of Existing Flame Arrestor and Stack

**Old Flame Arrester and Fuel Gas Piping**

**Old 8" Stack**

# Removal of Existing Flame Arrestor and Stack

# Installation of Flame Arrester Spool Piece
# Aux Burner and Stack

12" Aux Burner and Stack

Flame Arrester Spool Piece

# Flame Arrester Housing Stack Elbow

# Installation of Flame Arrestor with HP and LP Fuel Lines

High Pressure Piping to Main Burner

Low Pressure Piping to Main Burner

Low Pressure Piping to Aux Burner

## Aux Burner is installed in place of Exhaust Stack

- Rain Cap is required to insure proper operation of Aux Burner
- Existing 8" Stack is Replaced with a 12" Stack to accommodate the Aux Burner
- Aux Burner spool piece inserted at bottom of stack
- Spool piece has removable door for Air-Fuel Ratio adjustment and Burner inspection

# Dehy Low Pressure Vent Gas Piping

# High pressure valve train installed inside Dehy building. Minimal modification to fuel gas piping.

# Liquids Handling PVPA

## Prism Integrated Solutions

PVPA

# Liquids Handling
# Detonation  Arrestor and piping

# Liquids Handling
# Ruffneck Heater with VFD Driven Motor

Ruffneck Heater

# Ruffneck Heater, Arrestor and Piping

# SlipStream® *GTS-DeHy, Westerose Complete Installation*



PIC Solutions REM Technology Inc. SPARTAN Controls BEST MANAGED COMPANIES

# APPENDIX C

## Wild River Installation Details

## Presentation Materials Courtesy of Spartan Controls

# *Wild River Dehy Unit:*

- 280,000 BTU/hr. burner
- 8" fire tube and exhaust stack
- Kimray glycol pump.

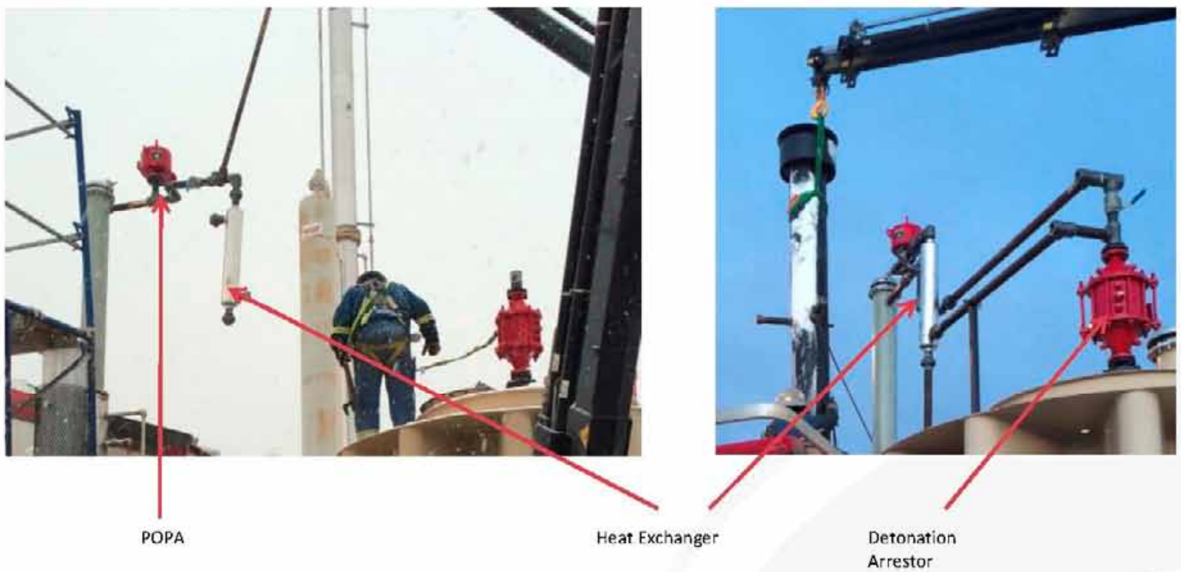

Tank Safe Exists

# Existing Flame Arrestor and Stack


# Installation of Flame Arrester Aux Burner and Stack

# Flame Arrester and Stack Elbow

# Liquids Handling POPA (Pressure Only Pipe Away), Heat Exchanger and Detonation Arrestor



# Hazloc Heater with VFD Driven Motor


# Vent Capture Tank

# SlipStream GTS Dehy System



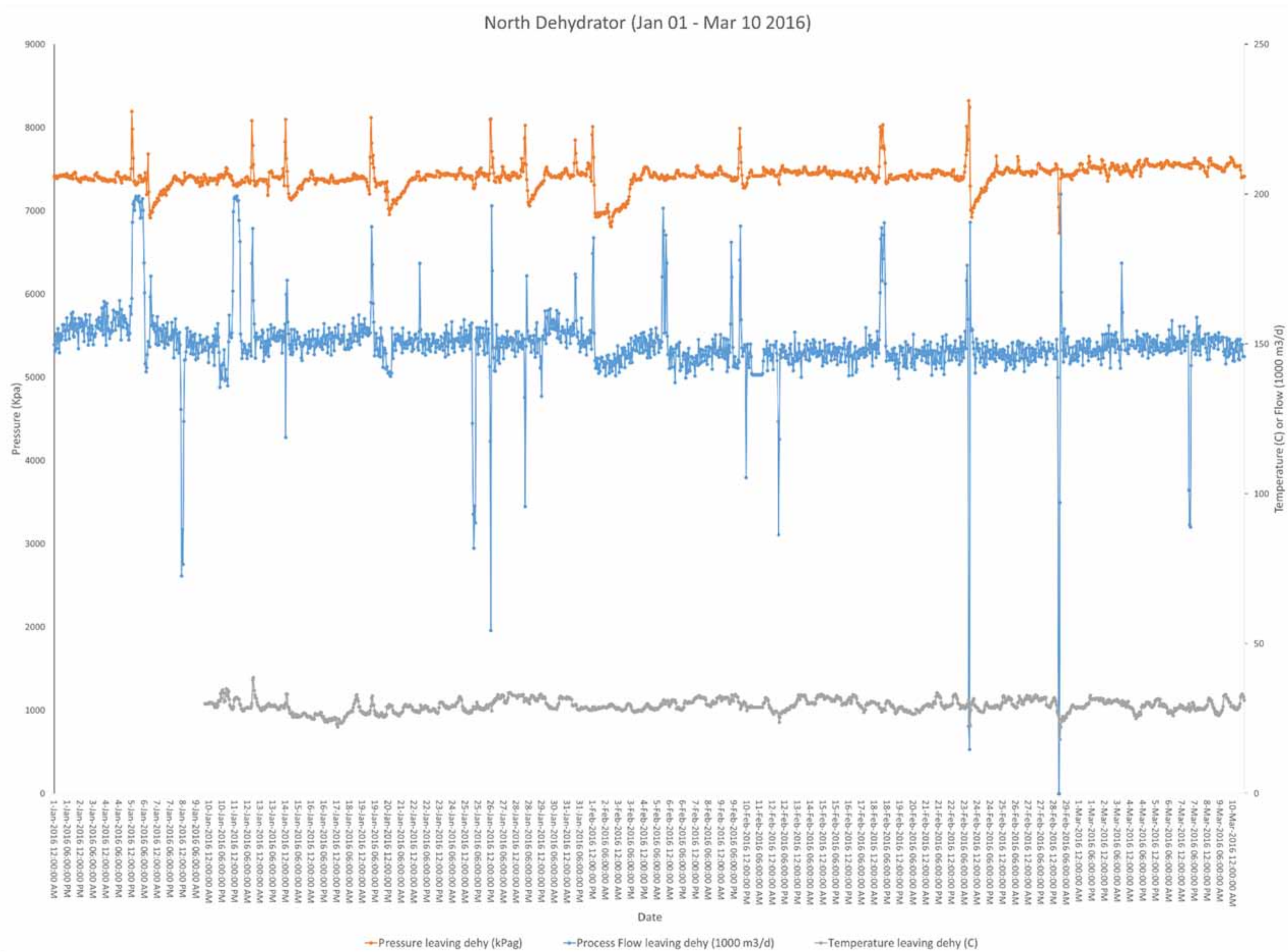

SPARTAN Controls

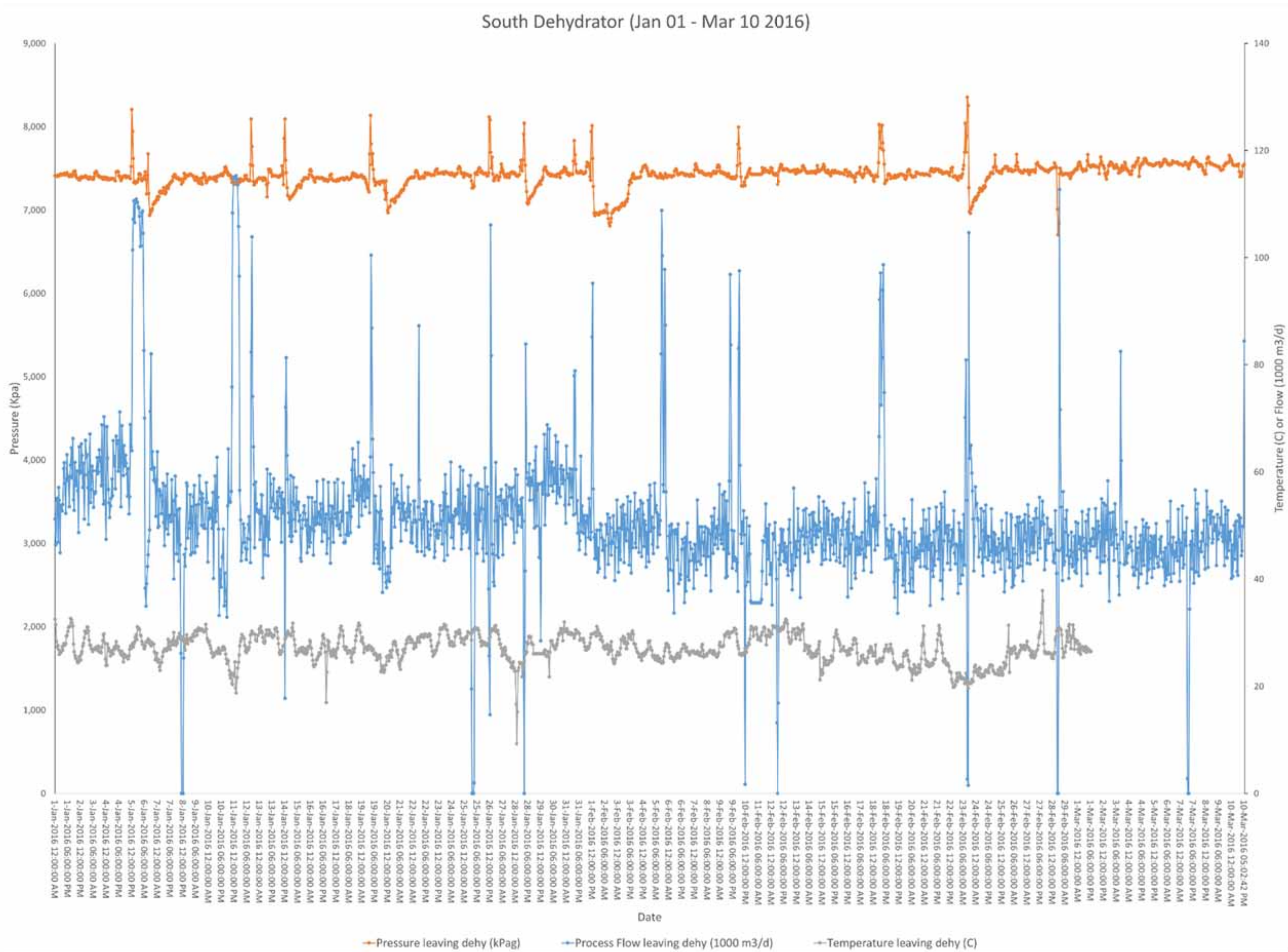
BEST MANAGED COMPANIES

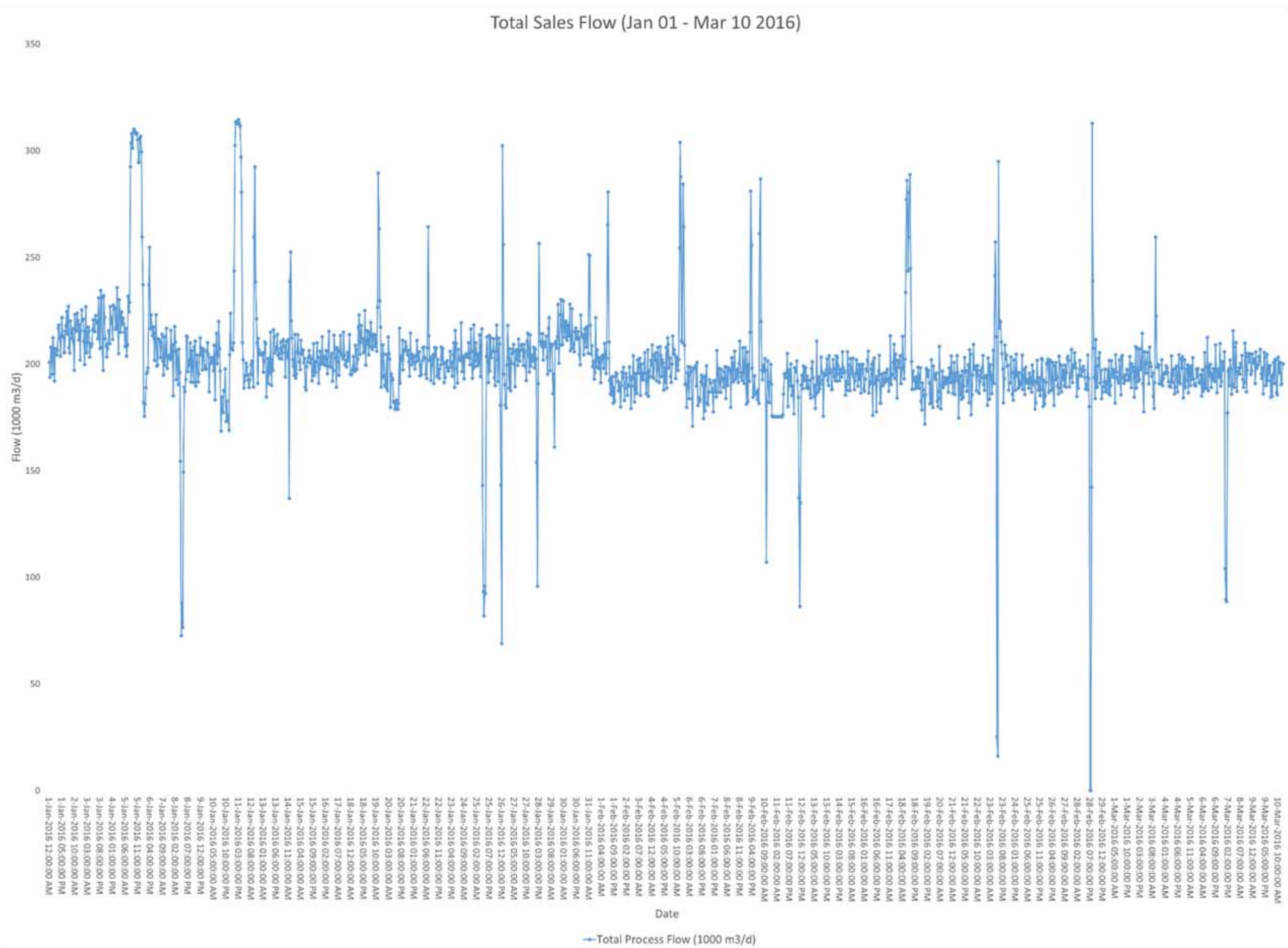
# APPENDIX D

## Westerose Plant Flows and Pressures

## January through March 10 2016


North Dehydrator (Jan 01 - Mar 10 2016)
Pressure (Kpa)
Temperature (C) or Flow (1000 m3/d)
Date
Pressure leaving dehy (kPag)
Process Flow leaving dehy (1000 m3/d)
Temperature leaving dehy (C)

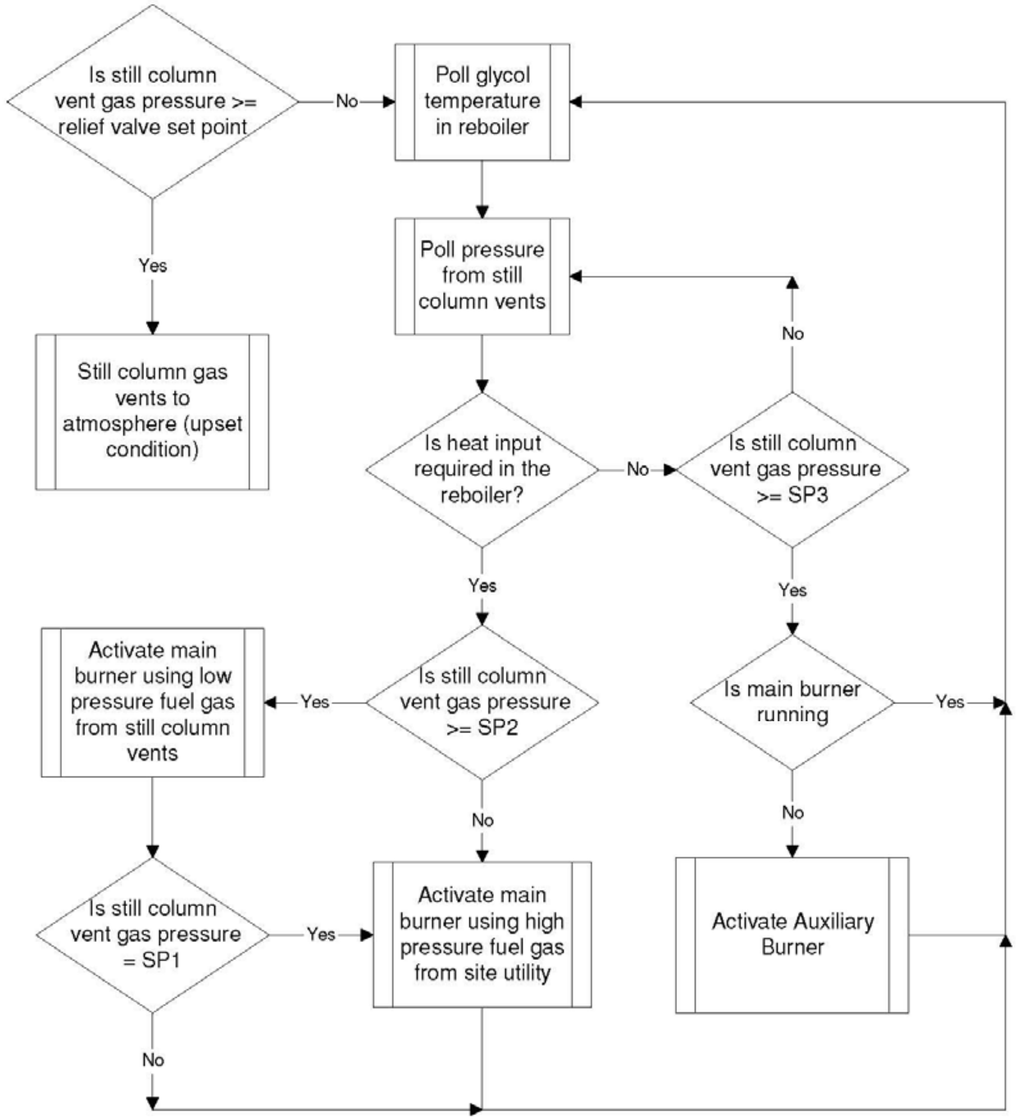

South Dehydrator (Jan 01 - Mar 10 2016)
Pressure (Kpa)
Temperature (C) or Flow (1000 m3/d)
Date
Pressure leaving dehy (kPag)
Process Flow leaving dehy (1000 m3/d)
Temperature leaving dehy (C)


Total Sales Flow (Jan 01 - Mar 10 2016)
Flow (1000 m3/d)
350
300
250
200
150
100
50
0
1-Jan-2016 12:00:00 AM
1-Jan-2016 05:00:00 PM
2-Jan-2016 10:00:00 AM
3-Jan-2016 03:00:00 AM
3-Jan-2016 08:00:00 PM
4-Jan-2016 01:00:00 PM
5-Jan-2016 06:00:00 AM
5-Jan-2016 11:00:00 PM
6-Jan-2016 04:00:00 PM
7-Jan-2016 09:00:00 AM
8-Jan-2016 02:00:00 AM
8-Jan-2016 07:00:00 PM
9-Jan-2016 12:00:00 PM
10-Jan-2016 05:00:00 AM
10-Jan-2016 10:00:00 PM
11-Jan-2016 03:00:00 PM
12-Jan-2016 08:00:00 AM
13-Jan-2016 01:00:00 AM
13-Jan-2016 06:00:00 PM
14-Jan-2016 11:00:00 AM
15-Jan-2016 04:00:00 AM
15-Jan-2016 09:00:00 PM
16-Jan-2016 02:00:00 PM
17-Jan-2016 07:00:00 AM
18-Jan-2016 12:00:00 AM
18-Jan-2016 05:00:00 PM
19-Jan-2016 10:00:00 AM
20-Jan-2016 03:00:00 AM
20-Jan-2016 08:00:00 PM
21-Jan-2016 01:00:00 PM
22-Jan-2016 06:00:00 AM
22-Jan-2016 11:00:00 PM
23-Jan-2016 04:00:00 PM
24-Jan-2016 09:00:00 AM
25-Jan-2016 02:00:00 AM
25-Jan-2016 07:00:00 PM
26-Jan-2016 12:00:00 PM
27-Jan-2016 05:00:00 AM
27-Jan-2016 10:00:00 PM
28-Jan-2016 03:00:00 PM
29-Jan-2016 08:00:00 AM
30-Jan-2016 01:00:00 AM
30-Jan-2016 06:00:00 PM
31-Jan-2016 11:00:00 AM
1-Feb-2016 04:00:00 AM
1-Feb-2016 09:00:00 PM
2-Feb-2016 02:00:00 PM
3-Feb-2016 07:00:00 AM
4-Feb-2016 12:00:00 AM
4-Feb-2016 05:00:00 PM
5-Feb-2016 10:00:00 AM
6-Feb-2016 03:00:00 AM
6-Feb-2016 08:00:00 PM
7-Feb-2016 01:00:00 PM
8-Feb-2016 06:00:00 AM
8-Feb-2016 11:00:00 PM
9-Feb-2016 04:00:00 PM
10-Feb-2016 09:00:00 AM
11-Feb-2016 02:00:00 AM
11-Feb-2016 07:00:00 PM
12-Feb-2016 12:00:00 PM
13-Feb-2016 05:00:00 AM
13-Feb-2016 10:00:00 PM
14-Feb-2016 03:00:00 PM
15-Feb-2016 08:00:00 AM
16-Feb-2016 01:00:00 AM
16-Feb-2016 06:00:00 PM
17-Feb-2016 11:00:00 AM
18-Feb-2016 04:00:00 AM
18-Feb-2016 09:00:00 PM
19-Feb-2016 02:00:00 PM
20-Feb-2016 07:00:00 AM
21-Feb-2016 12:00:00 AM
21-Feb-2016 05:00:00 PM
22-Feb-2016 10:00:00 AM
23-Feb-2016 03:00:00 AM
23-Feb-2016 08:00:00 PM
24-Feb-2016 01:00:00 PM
25-Feb-2016 06:00:00 AM
25-Feb-2016 11:00:00 PM
26-Feb-2016 04:00:00 PM
27-Feb-2016 09:00:00 AM
28-Feb-2016 02:00:00 AM
28-Feb-2016 07:00:00 PM
29-Feb-2016 12:00:00 PM
1-Mar-2016 05:00:00 AM
1-Mar-2016 10:00:00 PM
2-Mar-2016 03:00:00 PM
3-Mar-2016 08:00:00 AM
4-Mar-2016 01:00:00 AM
4-Mar-2016 06:00:00 PM
5-Mar-2016 11:00:00 AM
6-Mar-2016 04:00:00 AM
6-Mar-2016 09:00:00 PM
7-Mar-2016 02:00:00 PM
8-Mar-2016 07:00:00 AM
9-Mar-2016 12:00:00 AM
9-Mar-2016 05:00:00 PM
10-Mar-2016 10:00:00 AM
Date
Total Process Flow (1000 m3/d)

# APPENDIX E

## Data analysis for the Westerose Site

## SlipStream GTS-Dehy Burner Logic



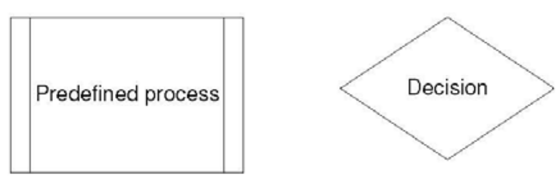

### Legend

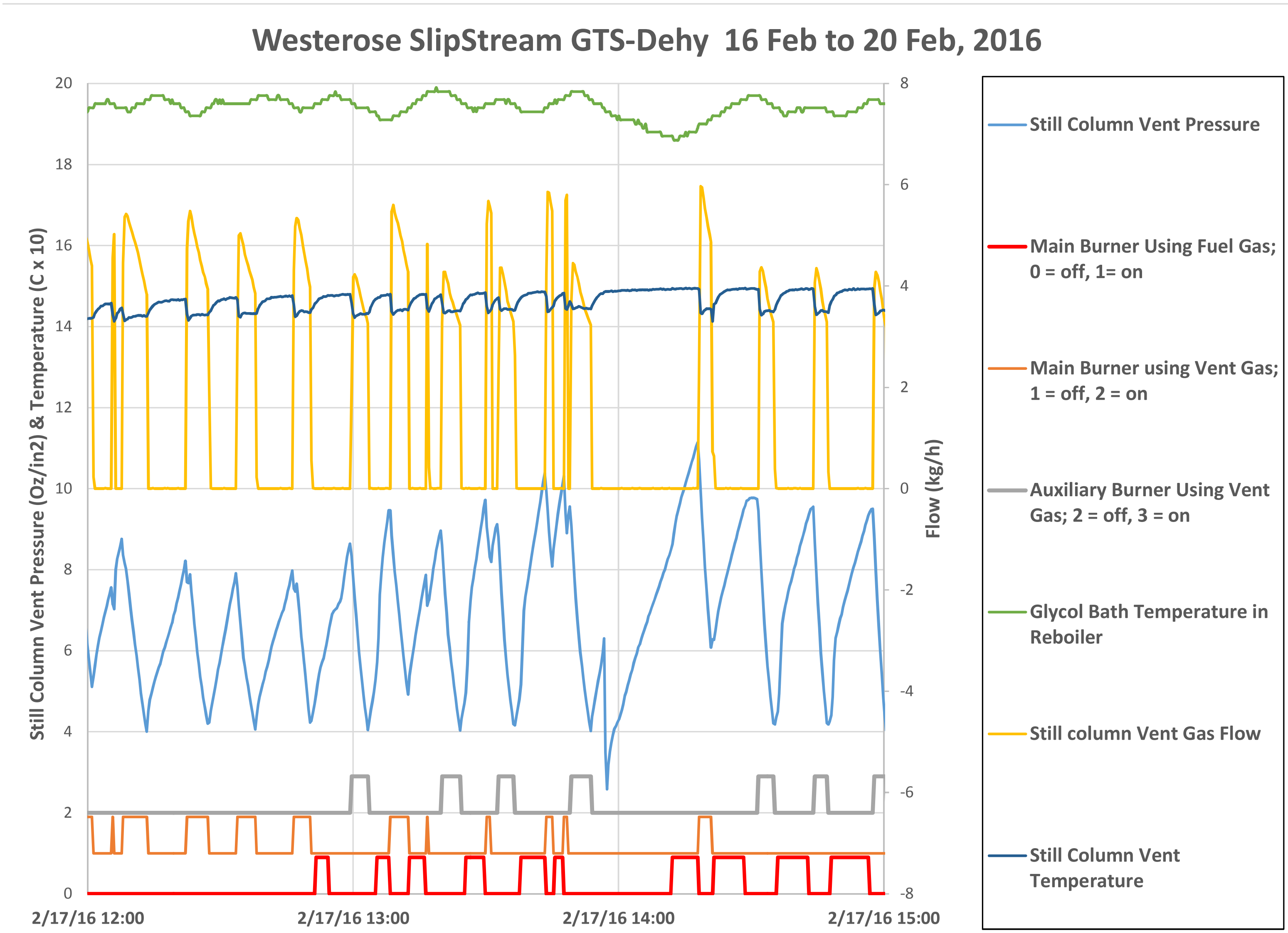
SP1 = pressure set point 1

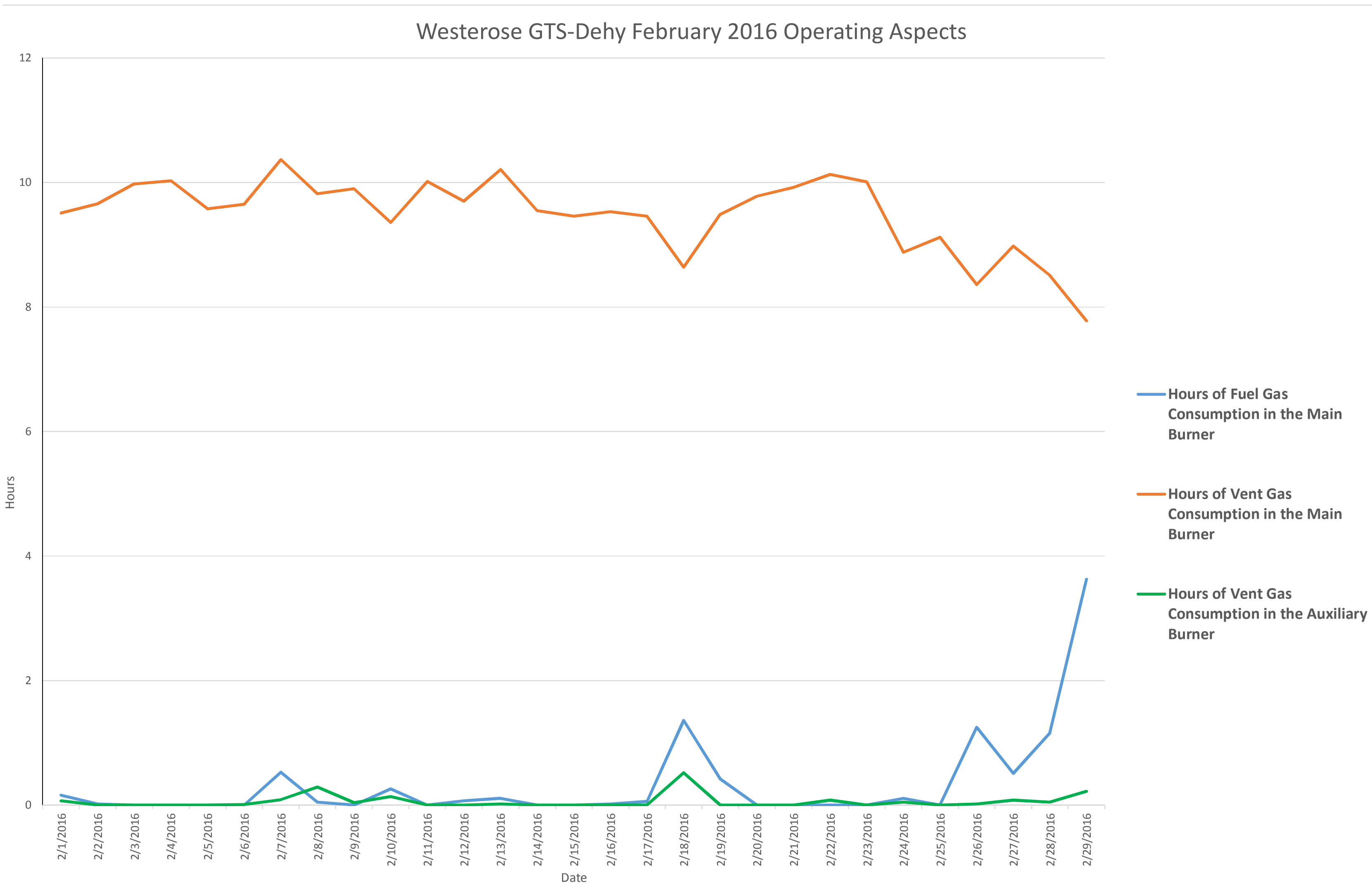
SP2 = pressure set point 2

SP3 = pressure set point 3

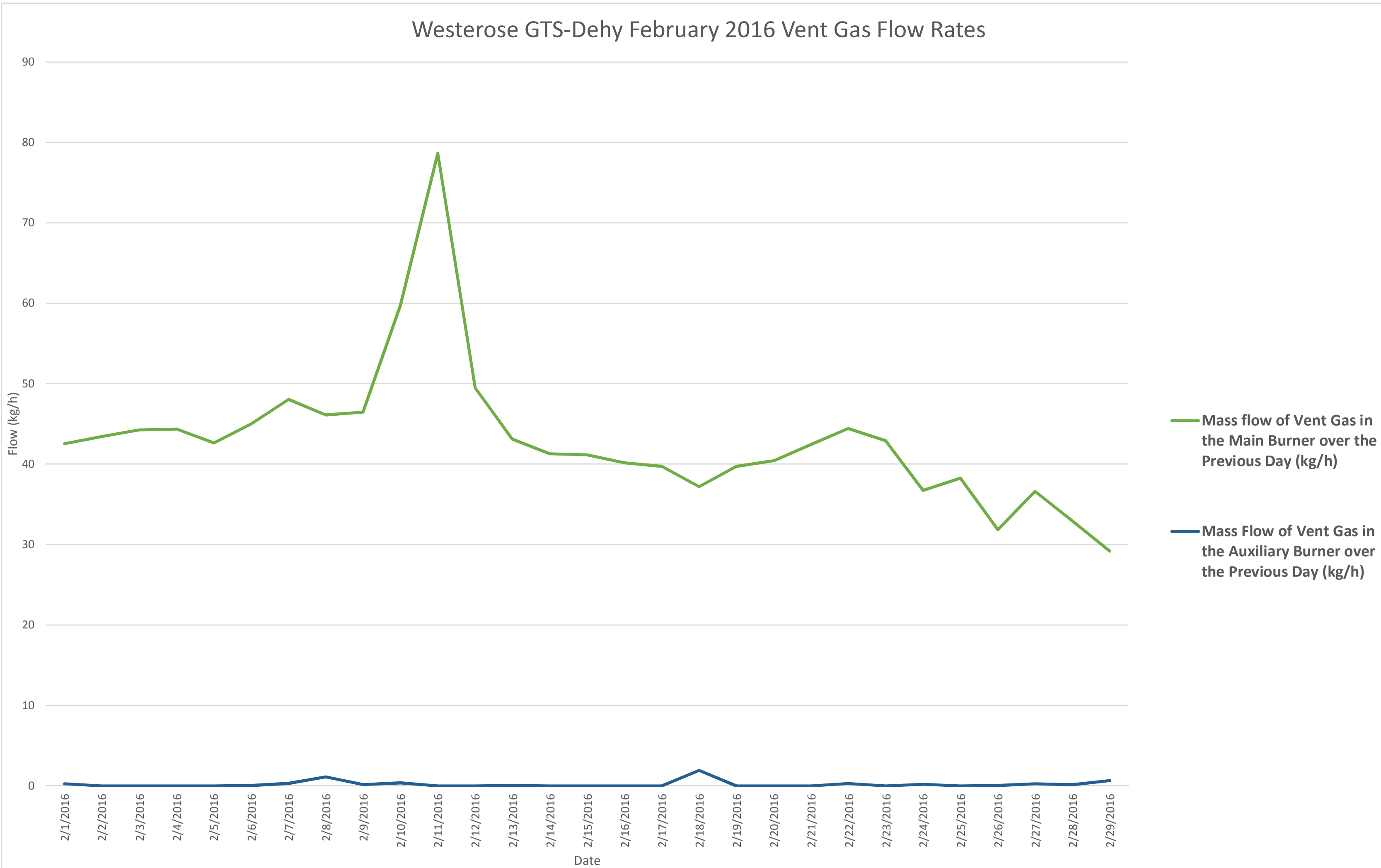
SP1 < SP2 < SP3




Westerose SlipStream GTS-Dehy 16 Feb to 20 Feb, 2016
Still Column Vent Pressure (Oz/in2) & Temperature (C x 10)
20
18
16
14
12
10
8
6
4
2
0
Flow (kg/h)
8
6
4
2
0
-2
-4
-6
-8
2/17/16 12:00
2/17/16 13:00
2/17/16 14:00
2/17/16 15:00
Still Column Vent Pressure
Main Burner Using Fuel Gas; 0 = off, 1= on
Main Burner using Vent Gas; 1 = off, 2 = on
Auxiliary Burner Using Vent Gas; 2 = off, 3 = on
Glycol Bath Temperature in Reboiler
Still column Vent Gas Flow
Still Column Vent Temperature



Westerose GTS-Dehy February 2016 Operating Aspects
Hours
12
10
8
6
4
2
0
2/1/2016
2/2/2016
2/3/2016
2/4/2016
2/5/2016
2/6/2016
2/7/2016
2/8/2016
2/9/2016
2/10/2016
2/11/2016
2/12/2016
2/13/2016
2/14/2016
2/15/2016
2/16/2016
2/17/2016
2/18/2016
2/19/2016
2/20/2016
2/21/2016
2/22/2016
2/23/2016
2/24/2016
2/25/2016
2/26/2016
2/27/2016
2/28/2016
2/29/2016
Date
Hours of Fuel Gas Consumption in the Main Burner
Hours of Vent Gas Consumption in the Main Burner
Hours of Vent Gas Consumption in the Auxiliary Burner



Westerose GTS-Dehy February 2016 Vent Gas Flow Rates
Flow (kg/h)
0
10
20
30
40
50
60
70
80
90
2/1/2016
2/2/2016
2/3/2016
2/4/2016
2/5/2016
2/6/2016
2/7/2016
2/8/2016
2/9/2016
2/10/2016
2/11/2016
2/12/2016
2/13/2016
2/14/2016
2/15/2016
2/16/2016
2/17/2016
2/18/2016
2/19/2016
2/20/2016
2/21/2016
2/22/2016
2/23/2016
2/24/2016
2/25/2016
2/26/2016
2/27/2016
2/28/2016
2/29/2016
Date
Mass flow of Vent Gas in the Main Burner over the Previous Day (kg/h)
Mass Flow of Vent Gas in the Auxiliary Burner over the Previous Day (kg/h)

# APPENDIX F

# Westerose Benzene Destruction Efficiency

## SPARTAN CONTROLS SUMMARY TABLE

**GTS-DEHY**

| Test # | Start Time | Burner Tested | Pilot Fuel Sample | Vent Fuel Sample | Stack Sample | Vent Source | Fuel Gross Heat Rate (kJ/hr) | Benzene Inlet Rate (ng/J) | Maximum Benzene Emission Rate (ng/J) | Minimum Benzene Destruction Efficiency |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12:22 | Low-pressure Main | P1 | V1 | T1 LP | Both Dehys | 269342 | 347.25 | 0.091036 | 99.974% |
| 2 | 12:34 | Low-pressure Main | P1 | V2 | T2 LP | Both Dehys | 260628 | 340.26 | 0.041342 | 99.988% |
| 3 | 12:47 | Low-pressure Main | P1 | V3 | T3 LP | Both Dehys | 272050 | 347.48 | 0.039756 | 99.989% |
| 4 | 13:20 | Auxiliary | P1 | V4 | T4 Aux | Both Dehys | 157809 | 462.80 | 0.045901 | 99.990% |
| 5 | 13:33 | Auxiliary | P1 | V5 | T5 Aux | Both Dehys | 163978 | 467.10 | 0.024730 | 99.995% |
| 6 | 13:49 | Auxiliary | P1 | V6 | T6 Aux | Both Dehys | 163792 | 473.45 | 0.024137 | 99.995% |
| 7 | 14:32 | Auxiliary | P2 | V7 | T7 Aux | GTS Dehy only | 164519 | 468.79 | 0.098204 | 99.979% |
| 8 | 14:44 | Auxiliary | P2 | V8 | T8 Aux | GTS Dehy only | 163410 | 470.01 | 0.095874 | 99.980% |
| 9 | 14:58 | Auxiliary | P2 | V9 | T9 Aux | GTS Dehy only | 164682 | 473.56 | 0.094801 | 99.980% |
| 10 | 15:10 | Low-pressure Main | P2 | V10 | T10 LP | GTS Dehy only | 270320 | 354.41 | 0.208573 | 99.941% |
| 11 | 15:27 | Low-pressure Main | P2 | V11 | T11 LP | GTS Dehy only | 270221 | 352.21 | 0.210785 | 99.940% |
| 12 | 15:41 | Low-pressure Main | P2 | V12 | T12 LP | GTS Dehy only | 273949 | 359.01 | 0.180327 | 99.950% |

99.940% min
99.995% max
99.975% average
0.020% stdev

## SUMMARY

On February 17, 2016, the Air Services Group of Maxxam Analytics conducted a Specialty Test Survey on the GTS-DeHy stack at the Bonavista Energy Westrose facility located at 14-27-45-1 W5. Sampling was carried out to determine the concentrations of specialty parameters as requested by the project coordinator.

All sampling, analysis, and QA/QC for this project was performed by Maxxam Analytics and complies with the applicable protocols (Alberta Stack Sampling Code, Alberta Methods for Chemical Analysis of Atmospheric Pollutants and the Alberta Air Monitoring Directive). The results are therefore considered to be representative of the source during the testing period.

The summary of results are presented on the following pages. Reference conditions for this report are 20 degC and 760 mmHg.

Any deviations or modifications made to the sampling or analytical methods are outlined in Section 1.0 Discussion. On this basis, Maxxam is issuing this completed report to Bonavista Energy, Calgary, AB.

We trust that this report meets your requirements. If you have any questions regarding this project, please contact us at 403-478-9471 or toll-free at 1-800-386-7247.

# APPENDIX G

Still Column Vent Gas Analysis

Fuel Gas Analysis

Process Gas Analysis

Greenhouse Gas Calculations

Flue Gas Analysis

| Source of Emission | | Fuel for Combustion | | | | | Gas Vented to Atmosphere | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fuel Gas for Main Burner | Pilot Gas for Main Burner | Still Column Vent for Main Burner | Pilot Gas for Aux Burner | Still Column Vent for Aux Burner | Fuel Gas for Main Burner | Still Column Vent for Main Burner | Still Column Vent for Aux Burner |
| Before GTS-DeHy Installation | Fraction of time for demand | 0.41 | 1 | 0 | 0 | 0 | 0 | 0.40 | 0.0024 |
| | Mass Flow Rate (Kg/h) | 4.83 | 0.6 | 0 | 0 | 0 | 0 | 4.53 | 3.48 |
| | Ratio for mass and LHV | 0.81 | 1.00 | 1.00 | 1.00 | 0 | 0 | 1.00 | 1.00 |
| | Adjusted Mass Flow Rate | 3.92 | 0.60 | 0.00 | 0.00 | 0 | 0 | 4.53 | 3.48 |
| | GHG Emissions ($CO_2e$) | 37.6 | 14 | 0 | 0 | 0 | 0 | 94.8 | 0.4 |
| | Total $CO_2e$ (tonnes/y) | 147 | | | | | | | |
| After GTS-DeHy Installation | Fraction of time for demand | 0.014 | 0.43 | 0.40 | 0.0024 | 0.0024 | 0 | 0 | 0 |
| | Mass Flow Rate (Kg/h) | 4.53 | 1.62 | 4.53 | 0.19 | 3.48 | 0 | 0 | 0 |
| | Ratio for mass and LHV | 0.81 | 1.00 | 1.00 | 1.00 | 1 | 0 | 0 | 0 |
| | Adjusted Mass Flow Rate | 3.68 | 1.62 | 4.53 | 0.19 | 3.48 | 0 | 0 | 0 |
| | GHG Emissions ($CO_2e$) | 1.20 | 16.38 | 39.26 | 0.01 | 0.18 | 0 | 0 | 0 |
| | Total $CO_2e$ (tonnes/y) | 57 | | | | | | | |
| GHG Contribution Coefficients | Carbon Fraction | 0.72993 | 0.72993 | 0.68118 | 0.72993 | 0.68118 | 0.72993 | 0.68118 | 0.68118 |
| | CO2 Fraction | 0.04962 | 0.04962 | 0.19891 | 0.04962 | 0.19891 | 0.04962 | 0.19891 | 0.19891 |
| | CH4 Fraction | 0.63843 | 0.63843 | 0.23322 | 0.63843 | 0.23322 | 0.63843 | 0.23322 | 0.23322 |
| GHG Emission Change | CO2e Reduction (tonnes/y) | 90 | | | | | | | |

| Fuel Gas | Mol Fraction | Mols O2 Complete Combustion | Mols O2 per Mol component | Chemical Compound | Component Gram MW | O2 MW req for Fuel Combustion | Moles CO2 per mole Component | CO2 MW in Combustion Products | Density kg/m3 (15 deg C) | Fuel MW | LHV BTU/scf | LHV Contribution MJ/kg | Carbon Fraction | CO2 Fraction | CH4 Fraction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| METHANE | 0.8118 | 3 | 2.4354 | CH4 | 16.0423 | 38.9649 | 1 | 35.727 | 0.5508 | 13.0231 | 909.4 | 31.8 | 0.4776 | | 0.6384 |
| ETHANE | 0.0851 | 5 | 0.4255 | C2H6 | 30.0688 | 6.8077 | 2 | 7.490 | 0.1082 | 2.5589 | 1618.7 | 5.9 | 0.1001 | | |
| Acetylene | 0 | 3 | 0 | C2H2 | 26.0372 | 0.0000 | 2 | 0.000 | 0.0000 | 0.0000 | | 0.0 | 0.0000 | | |
| Ethene | 0 | 4 | 0 | C2H4 | 28.053 | 0.0000 | 2 | 0.000 | 0.0000 | 0.0000 | 1499 | 0.0 | 0.0000 | | |
| PROPANE | 0.0435 | 7 | 0.3045 | C3H8 | 44.0953 | 4.8718 | 3 | 5.743 | 0.0811 | 1.9181 | 2314.9 | 4.3 | 0.0768 | | |
| Propene | 0 | 6 | 0 | C3H6 | 42.0795 | 0.0000 | 3 | 0.000 | 0.0000 | 0.0000 | 2182 | 0.0 | 0.0000 | | |
| ISOBUTANE | 0.0062 | 9 | 0.0558 | C4H10 | 58.1218 | 0.8928 | 4 | 1.091 | 0.0152 | 0.3604 | 3000.4 | 0.8 | 0.0146 | | |
| N-BUTANE | 0.0107 | 9 | 0.0963 | C4H10 | 58.1218 | 1.5407 | 4 | 1.884 | 0.0263 | 0.6219 | 3010.8 | 1.4 | 0.0252 | | |
| ISOPENTANE | 0.0024 | 11 | 0.0264 | C5H12 | 72.1483 | 0.4224 | 5 | 0.528 | 0.0073 | 0.1732 | 3699 | 0.4 | 0.0071 | | |
| N-PENTANE | 0.0023 | 11 | 0.0253 | C5H12 | 72.1483 | 0.4048 | 5 | 0.506 | 0.0070 | 0.1659 | 3703.9 | 0.4 | 0.0068 | | |
| N-HEXANE | 0.0012 | 13 | 0.0156 | C6H14 | 86.1748 | 0.2496 | 6 | 0.317 | 0.0044 | 0.1034 | 4403.9 | 0.2 | 0.0042 | | |
| N-HEPTANE | 0.001 | 15 | 0.015 | C7H16 | 100.0749 | 0.2400 | 7 | 0.308 | 0.0042 | 0.1001 | 5100.3 | 0.2 | 0.0041 | | |
| CARBON DIOXIDE | 0.023 | 0 | 0 | CO2 | 44.0095 | 0.0000 | 1 | 1.012 | 0.0428 | 1.0122 | 0 | 0.0 | 0.0135 | 0.0496 | |
| NITROGEN | 0.0129 | 0 | 0 | N2 | 28.0134 | 0.0000 | 0 | 0.000 | 0.0153 | 0.3614 | 0 | 0.0 | 0.0000 | | |
| WATER | 0 | 0 | 0 | | 18.0152 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| HYDROGEN | 0 | 1 | 0 | H2 | 2.0158 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 273.9 | 0.0 | 0.0000 | | |
| Argon | 0 | 0 | 0 | Ar | 39.948 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| Oxygen | 0 | 0 | 0 | O2 | 31.9988 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| HELIUM | 0 | 0 | 0 | He | 4.0026 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| Sum Totals | 1.000 | | 3.3998 | | | 54.3948 | | 54.607 | 0.863 | 20.399 | | 45.5 | 0.7299 | 0.0496 | 0.6384 |

| Still Column Vent Gas | Mol Fraction | Mols O2 Complete Combustion | Mols O2 per Mol component | Chemical Compound | Component Gram MW | O2 MW req for Fuel Combustion | Moles CO2 per mole Component | CO2 MW in Combustion Products | Density kg/m3 (15 deg C) | Fuel MW | LHV BTU/scf | LHV Contribution MJ/kg | Carbon Fraction | CO2 Fraction | CH4 Fraction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| METHANE | 0.46845 | 3 | 1.4053512 | CH4 | 16.0423 | 22.4848 | 1 | 20.616 | 0.3178 | 7.5150 | 909.4 | 11.6 | 0.1745 | | 0.2332 |
| ETHANE | 0.126769 | 5 | 0.633843 | C2H6 | 30.0688 | 10.1411 | 2 | 11.158 | 0.1612 | 3.8118 | 1618.7 | 5.6 | 0.0944 | | |
| Acetylene | 0 | 3 | 0 | C2H2 | 26.0372 | 0.0000 | 2 | 0.000 | 0.0000 | 0.0000 | | 0.0 | 0.0000 | | |
| Ethene | 0 | 4 | 0 | C2H4 | 28.053 | 0.0000 | 2 | 0.000 | 0.0000 | 0.0000 | 1499 | 0.0 | 0.0000 | | |
| PROPANE | 0.101571 | 7 | 0.7109942 | C3H8 | 44.0953 | 11.3755 | 3 | 13.410 | 0.1894 | 4.4788 | 2314.9 | 6.4 | 0.1135 | | |
| Propene | 0 | 6 | 0 | C3H6 | 42.0795 | 0.0000 | 3 | 0.000 | 0.0000 | 0.0000 | 2182 | 0.0 | 0.0000 | | |
| ISOBUTANE | 0.01761 | 9 | 0.1584855 | C4H10 | 58.1218 | 2.5357 | 4 | 3.100 | 0.0433 | 1.0235 | 3000.4 | 1.4 | 0.0262 | | |
| N-BUTANE | 0.041446 | 9 | 0.3730095 | C4H10 | 58.1218 | 5.9679 | 4 | 7.296 | 0.1019 | 2.4089 | 3010.8 | 3.4 | 0.0617 | | |
| ISOPENTANE | 0.013037 | 11 | 0.1434048 | C5H12 | 72.1483 | 2.2944 | 5 | 2.869 | 0.0398 | 0.9406 | 3699 | 1.3 | 0.0243 | | |
| N-PENTANE | 0.014594 | 11 | 0.1605285 | C5H12 | 72.1483 | 2.5684 | 5 | 3.211 | 0.0445 | 1.0529 | 3703.9 | 1.5 | 0.0272 | | |
| N-HEXANE | 0.011091 | 13 | 0.144183 | C6H14 | 86.1748 | 2.3068 | 6 | 2.929 | 0.0404 | 0.9558 | 4403.9 | 1.3 | 0.0248 | | |
| N-HEPTANE | 0.030841 | 15 | 0.4626135 | C7H16 | 100.0749 | 7.4015 | 7 | 9.501 | 0.1305 | 3.0864 | 5100.3 | 4.3 | 0.0804 | | |
| CARBON DIOXIDE | 0.145643 | 0 | 0 | CO2 | 44.0095 | 0.0000 | 1 | 6.410 | 0.2711 | 6.4097 | 0 | 0.0 | 0.0542 | 0.1989 | |
| NITROGEN | 0.001849 | 0 | 0 | N2 | 28.0134 | 0.0000 | 0 | 0.000 | 0.0022 | 0.0518 | 0 | 0.0 | 0.0000 | | |
| WATER | 0.027102 | 0 | 0 | | 18.0152 | 0.0000 | 0 | 0.000 | 0.0206 | 0.4882 | 0 | 0.0 | 0.0000 | | |
| HYDROGEN | 0 | 1 | 0 | H2 | 2.0158 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 273.9 | 0.0 | 0.0000 | | |
| Argon | 0 | 0 | 0 | Ar | 39.948 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| Oxygen | 0 | 0 | 0 | O2 | 31.9988 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| HELIUM | 0 | 0 | 0 | He | 4.0026 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| Sum Totals | 1.000 | | 4.1924132 | | | 67.0761 | | 80.500 | 1.363 | 32.223 | | 36.9 | 0.6812 | 0.1989 | 0.2332 |

| Process Gas | Mol Fraction | Mols O2 Complete Combustion | Mols O2 per Mol component | Chemical Compound | Component Gram MW | O2 MW req for Fuel Combustion | Moles CO2 per mole Component | CO2 MW in Combustion Products | Density kg/m3 (15 deg C) | Fuel MW | LHV BTU/scf | LHV Contribution MJ/kg | Carbon Fraction | CO2 Fraction | CH4 Fraction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| METHANE | 0.7993 | 3 | 2.3979 | CH4 | 16.0423 | 38.3650 | 1 | 35.177 | 0.5423 | 12.8226 | 909.4 | 30.3 | 0.4546 | | 0.6077 |
| ETHANE | 0.0845 | 5 | 0.4225 | C2H6 | 30.0688 | 6.7597 | 2 | 7.438 | 0.1075 | 2.5408 | 1618.7 | 5.7 | 0.0961 | | |
| Acetylene | 0 | 3 | 0 | C2H2 | 26.0372 | 0.0000 | 2 | 0.000 | 0.0000 | 0.0000 | | 0.0 | 0.0000 | | |
| Ethene | 0 | 4 | 0 | C2H4 | 28.053 | 0.0000 | 2 | 0.000 | 0.0000 | 0.0000 | 1499 | 0.0 | 0.0000 | | |
| PROPANE | 0.0452 | 7 | 0.3164 | C3H8 | 44.0953 | 5.0622 | 3 | 5.968 | 0.0843 | 1.9931 | 2314.9 | 4.4 | 0.0771 | | |
| Propene | 0 | 6 | 0 | C3H6 | 42.0795 | 0.0000 | 3 | 0.000 | 0.0000 | 0.0000 | 2182 | 0.0 | 0.0000 | | |
| ISOBUTANE | 0.0072 | 9 | 0.0648 | C4H10 | 58.1218 | 1.0368 | 4 | 1.267 | 0.0177 | 0.4185 | 3000.4 | 0.9 | 0.0164 | | |
| N-BUTANE | 0.013 | 9 | 0.117 | C4H10 | 58.1218 | 1.8719 | 4 | 2.288 | 0.0320 | 0.7556 | 3010.8 | 1.6 | 0.0296 | | |
| ISOPENTANE | 0.0037 | 11 | 0.0407 | C5H12 | 72.1483 | 0.6512 | 5 | 0.814 | 0.0113 | 0.2669 | 3699 | 0.6 | 0.0105 | | |
| N-PENTANE | 0.0039 | 11 | 0.0429 | C5H12 | 72.1483 | 0.6864 | 5 | 0.858 | 0.0119 | 0.2814 | 3703.9 | 0.6 | 0.0111 | | |
| N-HEXANE | 0.0032 | 13 | 0.0416 | C6H14 | 86.1748 | 0.6656 | 6 | 0.845 | 0.0117 | 0.2758 | 4403.9 | 0.6 | 0.0109 | | |
| N-HEPTANE | 0.0037 | 15 | 0.0555 | C7H16 | 100.0749 | 0.8880 | 7 | 1.140 | 0.0157 | 0.3703 | 5100.3 | 0.8 | 0.0147 | | |
| CARBON DIOXIDE | 0.0231 | 0 | 0 | CO2 | 44.0095 | 0.0000 | 1 | 1.017 | 0.0430 | 1.0166 | 0 | 0.0 | 0.0131 | 0.0482 | |
| NITROGEN | 0.0128 | 0 | 0 | N2 | 28.0134 | 0.0000 | 0 | 0.000 | 0.0152 | 0.3586 | 0 | 0.0 | 0.0000 | | |
| WATER | 0 | 0 | 0 | | 18.0152 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| HYDROGEN | 0 | 1 | 0 | H2 | 2.0158 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 273.9 | 0.0 | 0.0000 | | |
| Argon | 0 | 0 | 0 | Ar | 39.948 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| Oxygen | 0 | 0 | 0 | O2 | 31.9988 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| HELIUM | 0 | 0 | 0 | He | 4.0026 | 0.0000 | 0 | 0.000 | 0.0000 | 0.0000 | 0 | 0.0 | 0.0000 | | |
| Sum Totals | 1.000 | | 3.4993 | | | 55.9867 | | 56.812 | 0.892 | 21.100 | | 45.5 | 0.7342 | 0.0482 | 0.6077 |

See the table in Appendix F for the legend to the test results

**Westerose Fuel Gas Analysis at Dehy Inlets February 17 2016 (Maxxam)**

| Gas Stream | | P1 | P2 | Combined |
|---|---|---|---|---|
| Flow | | 1.00 | 1.00 | 2.00 |
| Flow Ratio | | 0.500 | 0.500 | |
| WATER | H2O | 0.00% | 0.00% | 0.00% |
| METHANE | C1 | 81.18% | 81.17% | 81.18% |
| ETHANE | C2 | 8.48% | 8.54% | 8.51% |
| PROPANE | C3 | 4.33% | 4.37% | 4.35% |
| ISOBUTANE | IC4 | 0.61% | 0.62% | 0.62% |
| N-BUTANE | NC4 | 1.06% | 1.07% | 1.07% |
| ISOPENTANE | IC5 | 0.24% | 0.24% | 0.24% |
| N-PENTANE | NC5 | 0.23% | 0.23% | 0.23% |
| N-HEXANE | C6 | 0.12% | 0.11% | 0.12% |
| N-HEPTANE | C7 | 0.13% | 0.06% | 0.10% |
| NITROGEN | N2 | 1.30% | 1.28% | 1.29% |
| CARBON DIOXIDE | CO2 | 2.30% | 2.29% | 2.30% |
| HYDROGEN SULFIDE | H2S | 0.00% | 0.00% | 0.00% |
| HYDROGEN | H2 | 0.00% | 0.00% | 0.00% |
| HELIUM | He | 0.02% | 0.02% | 0.02% |
| | | | | 0 |
| Total | | 100.00% | 100.00% | 100.00% |

**Westerose Still Column Vent Gas Analysis February 17 2016 (Maxxam)**

| Gas Stream | | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V9 | V11 | V12 | Combined |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12.00 |
| Flow Ratio | | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | |
| WATER | H2O | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| METHANE | C1 | 48.35% | 48.33% | 48.22% | 48.25% | 48.11% | 48.09% | 48.41% | 48.01% | 48.04% | 47.97% | 48.03% | 48.00% | 48.15% |
| ETHANE | C2 | 13.05% | 13.09% | 13.06% | 13.06% | 13.04% | 13.04% | 12.96% | 13.01% | 13.00% | 13.01% | 13.01% | 13.02% | 13.03% |
| PROPANE | C3 | 10.44% | 10.42% | 10.42% | 10.43% | 10.45% | 10.44% | 10.39% | 10.43% | 10.49% | 10.43% | 10.51% | 10.45% | 10.44% |
| ISOBUTANE | IC4 | 1.80% | 1.74% | 1.74% | 1.75% | 1.84% | 1.76% | 1.76% | 1.91% | 1.84% | 1.90% | 1.83% | 1.86% | 1.81% |
| N-BUTANE | NC4 | 4.20% | 4.21% | 4.22% | 4.24% | 4.27% | 4.26% | 4.26% | 4.31% | 4.28% | 4.31% | 4.29% | 4.29% | 4.26% |
| ISOPENTANE | IC5 | 1.31% | 1.31% | 1.32% | 1.33% | 1.33% | 1.34% | 1.34% | 1.35% | 1.35% | 1.35% | 1.35% | 1.35% | 1.34% |
| N-PENTANE | NC5 | 1.47% | 1.47% | 1.48% | 1.49% | 1.49% | 1.50% | 1.50% | 1.51% | 1.52% | 1.52% | 1.52% | 1.52% | 1.50% |
| N-HEXANE | C6 | 1.12% | 1.11% | 1.13% | 1.11% | 1.15% | 1.14% | 1.13% | 1.14% | 1.16% | 1.15% | 1.16% | 1.16% | 1.14% |
| N-HEPTANE + | C7+ | 3.05% | 3.03% | 3.15% | 3.08% | 3.10% | 3.20% | 3.15% | 3.19% | 3.24% | 3.26% | 3.27% | 3.31% | 3.17% |
| NITROGEN | N2 | 0.20% | 0.18% | 0.21% | 0.19% | 0.24% | 0.19% | 0.19% | 0.18% | 0.18% | 0.19% | 0.18% | 0.18% | 0.19% |
| CARBON DIOXIDE | CO2 | 15.01% | 15.11% | 15.05% | 15.07% | 14.98% | 15.04% | 14.91% | 14.96% | 14.90% | 14.91% | 14.85% | 14.86% | 14.97% |
| HYDROGEN SULFIDE | H2S | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| HYDROGEN | H2 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| HELIUM | He | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| | | | | | | | | | | | | | | |
| Total | | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |

**Westerose Process Gas Analysis at Dehy Inlets February 17 2016 (Maxxam)**

| Gas Stream | | North Dehy | South Dehy | Combined |
|---|---|---|---|---|
| Flow | | 150.00 | 50.00 | 200.00 |
| Flow Ratio | | 0.750 | 0.250 | |
| WATER | H2O | 0.00% | 0.00% | 0.00% |
| METHANE | C1 | 79.61% | 80.88% | 79.93% |
| ETHANE | C2 | 8.44% | 8.49% | 8.45% |
| PROPANE | C3 | 4.58% | 4.32% | 4.52% |
| ISOBUTANE | IC4 | 0.75% | 0.64% | 0.72% |
| N-BUTANE | NC4 | 1.37% | 1.10% | 1.30% |
| ISOPENTANE | IC5 | 0.40% | 0.27% | 0.37% |
| N-PENTANE | NC5 | 0.43% | 0.28% | 0.39% |
| N-HEXANE | C6 | 0.35% | 0.21% | 0.32% |
| N-HEPTANE | C7 | 0.43% | 0.25% | 0.39% |
| NITROGEN | N2 | 1.29% | 1.26% | 1.28% |
| CARBON DIOXIDE | CO2 | 2.32% | 2.28% | 2.31% |
| HYDROGEN SULFIDE | H2S | 0.00% | 0.00% | 0.00% |
| HYDROGEN | H2 | 0.00% | 0.00% | 0.00% |
| HELIUM | He | 0.03% | 0.02% | 0.03% |
| | | | | 0 |
| Total | | 100.00% | 100.00% | 100.00% |
| Temperature, degrees C | | 30.0 | 30.0 | 30.0 |
| Temperature, degrees F | | 86.0 | 86.0 | 86.0 |
| Mole Weight, dry | | 21.300 | 20.600 | 21.125 |
| Density kg/m3, dry (15 C) | | 0.903 | 0.875 | 0.896 |
| Density lb/ft3, dry @ (15 C) | | 119.438 | 117.478 | 0.056 |
| Relative Density, dry | | 0.737 | 0.714 | 0.731 |
| Gross Heating Value (MJ/m3) | | 45.330 | 44.090 | 45.020 |
| C7+ Mole Weight, dry | | 97.500 | 95.900 | 97.100 |
| C7+ Density kg/m3, dry (15 C) | | 4.136 | 4.066 | 4.118 |
| C7+ Density lb/ft3, dry (15 C) | | 0.258 | 0.254 | 0.257 |
| C7+ Relative Density, dry | | 3.376 | 3.319 | 3.362 |
| C7+ Gross Heating Value (MJ/m3) | | 194.870 | 191.040 | 193.913 |

| Westerose Main Burner Exhaust Gas Analysis on Vent Gas February 17 2016 (Maxxam) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gas Stream | | Test 1 | Test 2 | Test 3 | Test 10 | Test 11 | Test 12 | Combined |
| Flow | | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| Flow Ratio | | 0.167 | 0.167 | 0.167 | 0.167 | 0.167 | 0.167 | |
| WATER | H2O | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| METHANE | C1 | 0.0004% | 0.0004% | 0.0004% | 0.0004% | 0.0004% | 0.0004% | 0.0004% |
| ETHANE | C2 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| PROPANE | C3 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| ISOBUTANE | IC4 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| N-BUTANE | NC4 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| ISOPENTANE | IC5 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| N-PENTANE | NC5 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| N-HEXANE | C6 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| N-HEPTANE + | C7+ | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| NITROGEN | N2 | 82.26% | 82.05% | 82.21% | 82.32% | 82.27% | 82.40% | 82.25% |
| CARBON DIOXIDE | CO2 | 8.26% | 7.77% | 8.07% | 8.17% | 8.09% | 8.24% | 8.10% |
| CARBON MONOXIDE | CO | 0.0017% | 0.0013% | 0.0010% | 0.0005% | 0.0004% | 0.0004% | 0.0009% |
| HYDROGEN SULFIDE | H2S | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| HYDROGEN | H2 | 0.05% | 0.05% | 0.05% | 0.05% | 0.05% | 0.05% | 0.05% |
| HELIUM | He | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| OXYGEN | O2 | 8.50% | 9.20% | 8.73% | 8.53% | 8.66% | 8.38% | 8.67% |
| ARGON | Ar | 0.98% | 0.98% | 0.98% | 0.98% | 0.98% | 0.99% | 0.98% |
| Total | | 100.05% | 100.05% | 100.04% | 100.05% | 100.05% | 100.06% | 100.05% |

| Westerose Aux Burner Exhaust Gas Analysis on Vent Gas February 17 2016 (Maxxam) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gas Stream | | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 | Test 9 | Combined |
| Flow | | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| Flow Ratio | | 0.167 | 0.167 | 0.167 | 0.167 | 0.167 | 0.167 | |
| WATER | H2O | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| METHANE | C1 | 0.0004% | 0.0004% | 0.0004% | 0.0004% | 0.0004% | 0.0004% | 0.0004% |
| ETHANE | C2 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| PROPANE | C3 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| ISOBUTANE | IC4 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| N-BUTANE | NC4 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| ISOPENTANE | IC5 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| N-PENTANE | NC5 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| N-HEXANE | C6 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| N-HEPTANE + | C7+ | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| NITROGEN | N2 | 80.50% | 80.36% | 80.47% | 80.35% | 80.43% | 80.46% | 80.43% |
| CARBON DIOXIDE | CO2 | 4.73% | 4.39% | 4.50% | 4.42% | 4.53% | 4.58% | 4.53% |
| CARBON MONOXIDE | CO | 0.0531% | 0.0290% | 0.0189% | 0.0088% | 0.0050% | 0.0048% | 0.0199% |
| HYDROGEN SULFIDE | H2S | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| HYDROGEN | H2 | 0.05% | 0.05% | 0.05% | 0.05% | 0.05% | 0.05% | 0.05% |
| HELIUM | He | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| OXYGEN | O2 | 13.75% | 14.26% | 14.05% | 14.26% | 14.07% | 13.99% | 14.06% |
| ARGON | Ar | 0.96% | 0.96% | 0.96% | 0.96% | 0.96% | 0.96% | 0.96% |
| Total | | 100.04% | 100.05% | 100.05% | 100.05% | 100.05% | 100.05% | 100.05% |